THE MEASUREMENT OF WIND PRESSURES ON TALL BUILDINGS

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SUMMARY

THE paper reviews some previous work on the measurement of wind pressures on the full scale and touches on the need for further research. It deals with some of the problems that arise in this work.

After outlining the scope of the current Building Research Station programme on the measurement of wind effects, the paper describes the pilot investigation being made at State House, Holborn, to develop suitable techniques and to study the effects of gusts on the pressure distribution.

1. INTRODUCTION

Builders have always had to contend with wind forces, and it is only natural that through the centuries, by a process of trial and error, the traditional constructions that have been evolved have generally been reasonably resistant to the effects of the wind. The safety factor has, however, often been only marginal and on occasions quite inadequate to meet abnormal wind storms, and recent experience indicates that there is a need for a re-assessment of current building practice to provide for the wind loads that are imposed on structures from time to time.

There have been, moreover, considerable changes in building techniques in recent years which have tended to make buildings more susceptible to the effects of wind. There is an increasing tendency to build high with the result that more buildings are exposed to higher wind speeds, and wind loadings are now assuming a greater significance in relation to the other forces imposed on the building. In addition to this, the use of lighter constructions and lightweight cladding units has made many modern buildings more responsive to short duration gusts, the effects of which are not yet fully understood, but which clearly involve the operation of forces greater than have hitherto been assumed to act. These features, together with the evidence of a number of structural failures due to wind action, have prompted a further investigation by the Building Research Station of the forces acting on buildings during strong winds.

The investigation of wind loads on structures has progressed, spasmodically, over at least eighty years. It was in 1884 that Baker[1] described experiments that he and Fowler had carried out to measure wind loads in connection with the building of the Forth Bridge; and then in 1925 came Stanton's[2] work on the Tower Bridge. In both of these investigations there was an objective to measure the pressures on various parts of the structure and, additionally, to determine the difference of pressure as between a localized point on the structure and a more extensive section of it, i.e. to investigate the effect of the gustiness of the natural wind. Both Baker and Stanton made advances in the knowledge of wind action on structures but the instrumentation available at the time was inadequate to deal with the complexity of the problems to be solved; nevertheless, these early experiments brought an awareness of the great field still to be explored.

One of the first attempts to measure the pattern of wind loading on a tall building was that carried out on the Empire State Building during 1932-36 and reported by Rathbun[3]. Pressure readings were obtained from a series of manometers connected by long pipes to pressure holes on the face of the building. The frequency response of such a system was inevitably too low for the gust pattern to be fully indicated, but the experiment gave a survey of the general pressure distribution, and this was compared with the pressure pattern obtained from a model of the same building tested in a wind tunnel[4]. It was concluded 'that the natural wind movements are not at all like those in a wind tunnel': but one is left with some doubt as to the validity of the pressure pattern obtained since the readings from different parts of the building were not simultaneous, and variation in the incident wind during the period of a set of readings seems to have been very probable.

At the present time there is need for much more data on wind loading to provide a rational basis for structural design. Most of the meteorological records available are of limited value to the structural engineer because they have been obtained largely from measurements in relatively open situations, such as airfields, which are not representative of the sites that generally interest the builder; and, moreover, they do not indicate directly the parameters of the wind that are the concern of the designer. It is widely recognized now that buildings can be damaged by wind pressures of comparatively short duration. If the wind force exceeds the strength of the building to withstand it, the occurrence and extent of damage will depend on the magnitude and duration of the force, the inertia of the building, and the response frequencies of the building and its several parts. The force durations necessary are seldom more than a few seconds, except in the case of long flexible structures such as suspension bridges, and may well be less than a second in the case of lightweight structural components.

Thus it is necessary to measure in detail the actual forces imposed locally on a structure, and to determine the overall loadings, on a time base appropriate to the structure, and to relate these in the most useful manner to the meteorological data currently available. The experimental work to be described was arranged to provide some of these data now urgently required by the designers of tall buildings: the wind speed at various heights over built-up areas: the characteristics of the gustiness: and the effects of these in producing pressures and suctions on the elements of structure.

2. PROBLEMS OF FULL-SCALE MEASUREMENT OF WIND PRESSURES

From the structural point of view the ideal way to determine wind effects on buildings would be to measure the total instantaneous load on complete units of cladding, and on the structure as a whole. Unfortunately this is generally impracticable and it is necessary to compromise by taking sample loadings at discrete points. This can be achieved by fitting wind-pressure gauges flush with the surface of selected buildings, the number and disposition of the gauges being controlled by the nature of the building and the particular programme appropriate to it. As suggested above, the gauges and the whole of the recording equipment should have a sufficiently high response frequency to be able to deal with pressure transients lasting only a fraction of a second (a suitable target is a time resolution to about 0.1 sec.); and the gauges must record continuously and simultaneously on to a common chart in order that the fluctuating pressure pattern on the building may be studied. These requirements virtually necessitate the use of pressure gauges having an electrical output.

A study of meteorological records covering wind and atmospheric pressure and temperature reveals a range of serious problems that must be overcome in any attempt to measure wind pressures on a building. The first, and most important of these is concerned with the range of pressures to be measured and the establishment of a reference pressure. It will be realized that, in any programme of wind-pressure measurement, the majority of readings will be in the range ± 10 lb/ft^2 and that seldom, even in severe storms, will pressures measured on the cladding exceed 30 lb/ft^2 relative to the barometric pressure. Yet, during the period of recording, the barometric pressure itself may change by as much as 200 lb/ft^2; and even during relatively short periods of recording the change of barometric pressure may exceed the pressure variations due to the wind. It is fortunate that barometric changes are generally sufficiently slow for external and internal pressures on a building to become equalized. This large variation of barometric pressure makes it preferable to record wind pressures as increments on the barometric rather than as absolute pressures; that is, changes in the barometer should not affect the readings of the wind pressure gauges. Thus, the pressure capsules employed should not be sealed. They should be open at the back to the atmosphere, but this poses yet another problem: what reference pressure should be adopted? The pressure inside a building or a room will depend on the wind flow around the building and on the amount and distribution of door and window openings, and it may vary from place to place in the building. A gauge directly open at the back will indicate the difference between the external and internal pressures at that point on the building, i.e. the total loading imposed locally on the wall. In some circumstances, this may be the indication required: but, if there are significant pressure differences between different parts of the interior of the building, there will be no common datum for the several gauges in use and it will not be possible to establish the true external pressure pattern or to determine the total external load on the structure. For this it is essential to have a common reference pressure for all gauges. This is being achieved in some of the Building Research Station's installations by running an air pipe from each gauge to a common reservoir which is open to atmosphere but installed in a situation protected as far as possible from external influences other than the normal excursions of the barometer. One necessary precaution in arranging such a system is to minimize the stack effect in any vertical run of pipe. In a warm building this could amount to about 0.5 lb/ft^2 for each 100 ft of height. A solution (in northern temperate regions) is to run the vertical pipe connections externally on the north face of the building where they are exposed to atmospheric temperature but screened from solar radiation.

It will be appreciated that the installation of wind-pressure recording equipment is a complex process and will need to be tailored to the particular building to be studied. For this reason it is desirable to plan the installation during the design stages of the building, and to build in the cables and pipe work in phase with the construction and to install the gauges or their mounts as the cladding progresses. A drawback to such a process is the time taken in building construction. For any major building it is likely to be at least two years after planning the experiment before any wind-pressure measurements can be made. Nevertheless, the advantages of such a procedure appear to justify the method for a major experiment, and most of the Building Research Station's work on wind-pressure measurement has been planned on these lines. An alternative method, which has some disadvantages, but which has been used as a matter of expediency, is to utilize an existing building and to mount wind-pressure gauges in the windows, with connections run as may be convenient.

One other major problem that must be referred to is that of correlating the wind-pressure measurements with the wind conditions prevailing at the time. It is not very probable that pressure measurements will be actually in progress at the very time when maximum loading of the building occurs. Measurements will be made under a variety of wind conditions and must be related to those conditions. Then by extrapolation, maximum probable loadings during the life of the building will be determined by reference to the maximum probable wind speeds estimated from the long term meteorological observations most appropriate to the site. But the measurement of wind speeds incident on a large building presents great difficulties. Ideally an anemometer is required to windward, separated from the building by a sufficient distance so that it will be out of the influence of the building itself: for large buildings tend to deflect and modify the wind flow for an appreciable distance around themselves, in every direction. To meet the conditions of winds from various directions it would be necessary to erect an array of anemometers, but this is usually impracticable. Often the most promising solution is to mount an anemometer on a mast on the roof of the building; but a tall mast is required to reach clear of the local disturbances, and this is not always acceptable to architects and town-planning authorities. Moreover, the fact must be taken into consideration that wind speed and turbulence varies with height and that the anemometer must not be unduly remote from the levels where pressure measurements are to be made. It seems that there can be no complete and perfect solution to this problem of correlating wind speeds and their associated effects and extrapolating them to the probable maximum. Each case must be treated on its merits and the best compromise solution worked out.

3. THE SCOPE OF THE CURRENT TESTS

The review of the previous work on wind loading which had been a necessary preliminary to the present investigation had revealed the need for further research in a number of directions, particularly in the field of full-scale experiment needed to check the validity of wind-tunnel experiments on models. A consideration of the scope of even this single aspect of the subject showed that only a very limited range of experiment was possible, and it was decided to restrict the investigation in the first instance to the problem of tall buildings, because of the considerable interest and activity in this type of building at the present time and the paucity of information relating to it.

Search was made for suitable projects at the design stage and, with the assistance and co-operation of the architects and engineers concerned, two buildings of widely different character were selected, each to provide a part of the information being sought. The first of these buildings is representative of much that is under construction at the present time. It is of plain "match-box" form with a relatively smooth exterior surface and no excrescences that might unduly complicate the wind flow. It is 220 feet high, with a plan area of 140 feet by 58 feet. Known as Block F it is on the Barbican site in the City of London. It is relatively unobstructed by tall buildings to the west but is in the turbulent wake of other similar buildings to the east and north-east, and it will thus be possible to compare the wind-pressure pattern under differing conditions of flow. Block F is being instrumented with 48 pressure measuring points. They are installed on the 7th, 13th and 17th floors at heights of 86 feet, 152 feet and 196 feet above ground level, in an asymmetric pattern designed to utilize different wind directions to complement one another in building up the maximum yield of information on the pressure distribution. This array of gauges, selected groups of which feed their outputs simultaneously on to a multi-channel galvanometer recorder having a chart speed of about 3 inches/minute, will enable the pressure pattern to be studied in considerable detail to provide information on the extent and duration of gust action on the cladding.

The other building selected is the 580 feet high G.P.O. Tower in course of erection at the Museum Telephone Exchange in London. Use of this tower will allow measurements to be made over the greatest possible range of heights. It will go a long way to provide the urgently needed information on the vertical profile of the wind over London. The tower is circular in section and for the most part has an external diameter of 50 feet. This plan form of the tower is admirably suited for a test programme of this nature because it has no bias as regards wind direction: moreover the pressure distribution round a circular tower has been well established in the smooth flow of the wind tunnel and is available for comparison with the measurements in the natural wind. For this reason gauges are to be installed at 12 equally spaced positions round the tower at each of four levels, i.e. at approximately 155 feet, 215 feet, 335 feet and 505 feet above ground level. Additional gauges are being installed at intermediate levels on that part of the surface of the tower facing the prevailing SW winds in order to have as complete a vertical profile as possible of the wind from that quarter. These gauges should also yield information on the vertical extent of gusts, and the manner in which gusts affect a tall building.

Strain gauges have been fitted to the steel reinforcement in the concrete of the tower so that it will be possible to determine by calculation the total wind loading, and to compare this with the results obtained from the measurement of the wind pressure with the individual gauges.

At the tower site it has been possible to arrange for the measurement of wind speeds for direct comparison with the pressure measurements. The tower itself is to be surmounted by a 40 feet lattice mast which will carry an anemometer at a height of about 620 feet; and in addition there is available in the vicinity another lattice tower which will permit the mounting of anemometers at heights of about 250 feet and 130 feet with open exposure to all winds except those from the north.

As mentioned earlier, the installation of wind measuring equipment in buildings under construction is a long-drawn operation governed by the progress of building, and measurements will not be possible before the Spring of 1963 at Barbican and perhaps a year later at the G.P.O. tower. To provide some limited information at an earlier date, arrangements were made to instrument two existing buildings which, though not ideal for purposes of wind measurement, offered facilities that were of immediate value. One of these, the Millbank Tower, is the tallest building in London at the present time with a height of 387 feet. It is being equipped with wind-pressure gauges set flush with the walls near the centre lines of the west and south faces at heights of 80 feet, 150 feet, 220 feet, 275 feet and 325 feet and will be in operation shortly, to give some preliminary indication of the pressure characteristics over this height range.

The other building which has been instrumented for wind-pressure measurement is State House, in Holborn, London, which houses the Headquarters of D.S.I.R. State House is far from ideal for a general study of wind-pressure distribution because it has a complex plan form and has a series of external frames which interfere with the wind flow on the longer faces of the building. It had, however, the great advantage of being readily available and was considered to be suitable for a preliminary experiment. It has already yielded some interesting information on wind effects, details of which are given in the following section.

4. WIND-PRESSURE MEASUREMENTS AT STATE HOUSE

State House is a 15-storey office building having a plan form as shown in *fig.1*, with a wing of 9-storey height as indicated. It became available in August, 1961; and, because of its accessibility and the fact that it was the first building to be fitted with the equipment developed by the Building Research Station for this detailed study of wind pressures, the installation was regarded as a prototype to examine some of the characteristics of gust action and to give experience in the techniques of high-resolution wind-pressure recording.

Wind-pressure gauges were mounted in windows on the east and west faces of the south block at the 11th and the top storeys as indicated in *fig.1*. These faces were selected because they are free of obstructions such as encumber the other faces of the building (*fig.2*). The 11th and 15th storeys were chosen for instrumentation because the 11th is the lowest that is clear above the surrounding buildings, and the 15th because it gives the maximum possible separation from the 11th - a feature which appeared to be of value in this pilot study of gust action. It was realized that the top storey might prove to be too near the top edge of the building and that severe falling-off of the pressure coefficient might be found at this level, but this risk was accepted, and the decision has proved to have been justified, although, as will be shown by a survey of pressures inside the building by means of an aneroid barometer, pressures at the 15th floor are somewhat lower than at the 14th.

Four additional gauges were mounted on the south and north faces, as indicated in *fig.1*, not so much to study the pressures at these positions as to serve as intermediate markers to help identify gusts on their passage from end to end of the building.

The wind-pressure gauges are described in appendix A. They were mounted directly into windows as shown in *fig.3* and were connected by electrical cables to recording equipment installed in a room on the 15th floor. Because of the impracticability in this case of connecting all gauges to a common reference pressure, each gauge was made open at the back and thus relied on the pressure of the room in which it was situated as its datum.

There was, at the beginning of this experiment, no information, so far as could be discovered, about the pressure variations to be expected in any one room of the building nor of the pressure differences to be expected between different rooms. A preliminary survey was therefore made to investigate the scale of such possible variations since they might have an important bearing on the evaluation of the external pressures that would be indicated by the gauges in the windows. The survey was made by means of a sensitive aneroid barometer, readings of which were noted in various parts of the building, under various conditions of door and window openings, and on different occasions with different conditions of wind. In addition to noting the height of the barometer above ground level the time of each reading was noted so that allowance could be made for the variation of the barometric pressure with time.

It was found that, with a strong wind blowing, windows on the windward face of the building were generally closed. Under these conditions, pressure throughout the building was reasonably uniform (after allowing for height above ground level) and approximated to the external pressure on the leeward face. If, however, a window were open on the windward face and the door of the room closed the pressure in that room was subject to rapid fluctuation due to gust action, and the range of pressures was surprisingly large, being comparable with the probable range of external pressures. For example, in a westerly wind gusting generally to 41 m.p.h. with a maximum gust of 44 m.p.h. the corresponding dynamic pressure heads q being 4.2 lb/ft^2 and 4.8 lb/ft^2 respectively, typical pressures in west-facing rooms with windows partly open were:

on the 14th floor, 1.6 lb/ft^2 rising to 4.2 lb/ft^2 in gusts;

on the 15th floor, 1 lb/ft^2 rising to 2.8 lb/ft^2 in gusts;

all of these being relative to the prevailing pressure in the corridors at each floor level, which was, as mentioned above, approximately that of the leeward face of the building. Some windward rooms showed pressure surges of the order of 0.5 lb/ft^2 when the windows were nominally closed. This suggests that in some cases there may be errors of up to about 10% in the measured pressures on windward faces when the room pressure is taken as the datum, even though the windows are closed; and it emphasizes the advantage to be gained by using a common reference pressure for all gauges. Some details of the survey are given in appendix B.

Wind-pressure records were taken from time to time during 1962 under a variety of wind conditions. The installation was regarded as experimental and subject to development, and for the first part of the year the control was manual, the equipment being switched on when conditions were deemed favourable. It so happened that in the early part of the year there were several severe gales, but they mostly blew up with insufficient warning for the pressure recorder to be manned, and the records so far obtained cover only moderately strong winds. Automatic control gear has since been built and installed, and at the present time the equipment samples at regular intervals, for example, 10 minutes out of each hour, with provision for an over-riding control from an anemometer to continue to record if the wind speed exceeds a pre-determined value. Specimen records are shown in *figs.4, 5, 6* and *7.* It will be noticed that in each case 12 channels have been recorded, appropriate gauges having been selected to examine various features of the wind effect. It had originally been intended to record 24 channels on the chart, but such is the erratic nature of wind pressure, and so variable the trace amplitude, that it proved impracticable to crowd the traces. The chart speed was about 3 inches/min., the time base being at 1 sec. intervals in *fig.4*, and at 2 sec. intervals on the other charts.

Turning first to *fig.4*, which includes the whole array of gauges on the east face of the building, it is seen that there is a remarkable correspondence between the pressure patterns of all these gauges, down to the very fine details of gusts lasting only a second or two. The synchronization of the gust action over the area explored (40 feet high by 50 feet wide) under the action of an oblique, south-easterly wind is also quite striking. As will be seen at time 55, and also at 173 and 277, the lag in pressure rise between the gauges at 15E5 and 15E1 is about 1 sec. In the case of the first and second of these gusts there is no discernible lag between the 15th and 11th floors, while in the case of the gust at 277 the pressure rise occurred at the 15th floor about 1.1/2 secs. before it reached the 11th floor. Another feature which should be noted at this stage, and will be seen in most of the records, is the rapidity of pressure fluctuation; peak values being reached from near zero in less than 1 sec. on many occasions, and even reversals of loading from pressure to suction in similar time intervals.

There were few occasions when records could be obtained of winds blowing normal to one of the instrumented faces of the building. One of these records, though with winds gusting only to 25 m.p.h., is shown in *fig.5.* This record, as do the next two reproduced, covers gauges on both the east and west faces of the building, at 11th floor level, with two additional gauges added in each case. Gauges on the windward face indicate pressures that are consistently positive with the exception of 11W1, which is at the trailing edge of the face (the wind was not quite normal to the face). On the leeward face pressures are negligible on gauges 11E2 and 11E3, but the gauges towards the corners of the building indicate suctions at those positions. 15E3, at the centre of the leeward face, top floor, also indicates suction suggesting that negative pressures are operative all round the perimeter of the leeward face. A more complete examination of the effects with winds normal to the faces must await the occurrence of stronger winds from the appropriate directions.

Fig.6 shows a record with winds gusting generally up to 37 m.p.h. from the NE. The close similarity between gauges across the east face is seen again. Also well marked on this record is the variation of pressure intensity across the face, the pressures reaching a maximum at position 11E2, the second gauge from the leading edge, and falling to a minimum at 11E5, which is at the trailing edge of this face. The gust recorded at time 26 shows a progression across the east face in about 1 sec., but in general on this record the gust action is closely synchronized across the face at 11th floor level. This is particularly well shown at time 544 where a sudden pressure rise occurs simultaneously over the whole face. It is to be noted on this record that the gauges on the west, the leeward, face show very little variation of pressure and that the pressures are generally near zero (referred, of course, to the pressure inside the building). It is of interest that some positive surges were recorded on the leeward face, a feature that was later confirmed by watching fans that are installed in the windows of some rooms. These fans were specially arranged to be closeable to eliminate their effect on room pressures during particular tests, but, when open and not switched on, they were seen to reverse direction from time to time under the influence of the external pressure, on the leeward face. The effect of a southerly wind, that is, a wind blowing approximately parallel to the two instrumented faces of the building, is shown in *figs.7a* and *7b*. There is little in common in the pressure patterns of the two ends of the building except that both show a maximum of wind effect at the windward edges of the faces, and both show a preponderance of suction at these positions. The west face shows more wind activity suggesting that the wind direction was slightly from that quarter rather than square to the building and, in conformity with this, significant positive pressures occur as transients on the west face whilst the east face remains almost entirely under the influence of suction. The important feature to notice is the rapid and substantial pressure change from positive to negative and vice versa, particularly at position 11W1, and also at 11W2, and to a lesser extent on the other gauges on the west face. Many of the suction peaks, whilst substantial in intensity, are of very short duration and appear to cover not more than about three gauge positions simultaneously, that is, less than 30 feet width of the building face.

Since the automatic control equipment for the wind pressure recorder was put into operation in December 1962 the wind has been, up to the time of preparation of this paper, predominantly from the NE, which, although not a preferred direction as far as measurements at State House are concerned, has provided a long series of comparable records which have been examined in some detail. The purpose of this has been to explore the wind effects and to investigate methods of presenting them. This information is not generally applicable since, as stated earlier, State House is not a typical form of building. Some of the results together with some relating to a southerly wind, are presented in appendix C. The records were measured to determine the normal range of pressure peaks at each gauge position, and the extreme range. The latter is of some interest, but the former is regarded as a more useful parameter since it can be more readily correlated with the records of wind speed and direction. There can be no certainty that the extreme wind speeds were the same at State House and at the anemometer site which is on the Meteorological Office in Kingsway, about 1/4 mile away, though it seems reasonable to assume that the general level of gust speeds was similar, the anemometer at Kingsway being at about the level of the 15th floor of State House. Mean levels of the pressure at each gauge position for the duration of the record were also derived, but while these may be significant in the case of winds that are normal to the face of the building, it was found that they had little meaning when the wind direction was on to a corner. This was because swinging of the wind direction during gusts could cause alternate positive and negative pressure regions which, although significant in themselves, could have a mean approaching zero.

The mean pressure levels of each record were correlated with the dynamic pressure head of the corresponding wind speed measured at Kingsway, and a coefficient was derived expressing the pressure as a proportion of the dynamic head. This was done also for the normal range of gust pressures, relating them to the pressure heads of the normal gust speeds, and similarly for the extreme gusts. The results, which are given in appendix C, are summarized in *Tables 1* and *2*.

It is to be noted that, if the mean wind speed over the few minutes duration of the record had been taken as the basis of assessment and the pressures recorded during the maximum gusts had been related to the dynamic pressure heads of the mean wind speeds, the pressure coefficients would have been much higher, reaching +2.2 to - 1.2 for the east face under the action of NE winds and +1.4 to -2.3 for the west face under a S wind.

It will be seen that there are considerable variations in the pressure coefficients from one record to another, particularly in *Table 1*. Individual discrepancies are likely to be due to a lack of precise correlation between the recorded pressure and the recorded wind speed, which is a feature that it is intended to improve as far as possible in future experiments. While successive records from the same wind direction show similar trends of pressure distribution, the means of the several records show a marked regularity of pattern, and may well be a useful indication of the relative pressures around the building. It is of interest that the

Table 1

Pressure coefficients for NE winds

(a) Coefficients based on normal gust speeds at Kingsway

Time of Record	18.1.63 17.25		18.1.63 19.25		18.1.63 20.25		19.1.63 12.25		19.1.63 13.25		Mean	
Gauge position												
15E3	+.85	0	+.45	0	+.6	-.05	+.4	-.1	+.55	0	+.6	-.05
11E1	+.65	-.3	+.3	-.2	+.4	-.5	+.4	-.3	+.4	-.3	+.4	-.3
11E2	+.75	-.3	+.4	-.2	+.6	-.3	+.35	-.25	+.5	-.3	+.55	-.25
11E3	+.85	0	+.35	0	+.6	0	+.25	-.15	+.5	0	+.5	-.05
11E4	+.45	-.1	+.3	-.05	+.35	-.15	+.2	-.15	+.3	-.1	+.3	-.1
11E5	+.35	0	+.2	-.05	+.3	-.15	+.15	-.05	+.3	0	+.25	-.05
11W1	+.1	-.1	+.05	-.05	0	-.15	0	-.05	0	-.1	+.05	-.1
11W2	+.1	-.1	0	-.05	0	-.1	0	-.05	0	-.05	0	-.05
11W3	+.2	-.2	+.1	-.1	0	-.2	+.05	-.05	+.05	-.2	+.1	-.15
11W4	+.1	-.1	0	-.05	0	-.15	+.05	0	0	-.15	+.05	-.1
11W5	+.1	-.1	+.05	0	+.1	-.05	+.05	0	+.05	-.05	+.1	-.05
15NW	+.1	-.15	+.05	-.15	+.1	-.15	+.05	0	+.05	-.25	+.1	-.15
(b) Coefficients based on extreme gust speeds												
15E3	+.75	-.2	+.4	-.05	+.6	-.15	+.7	-.35	+.6	-.3	+.6	-.2
11E1	+.7	-.25	+.4	-.2	+.6	-.6	+.65	-.3	+.6	-.3	+.6	-.35
11E2	+.75	-.35	+.5	-.4	+.7	-.35	+.75	-.45	+.6	-.3	+.65	-.35
11E3	+.75	-.15	+.45	-.1	+.7	-.15	+.55	-.35	+.55	-.2	+.6	-.2
11E4	+.4	-.1	+.25	-.05	+.3	-.2	+.4	-.25	+.35	-.15	+.35	-.15
11E5	+.4	-.05	+.15	-.1	+.3	-.25	+.25	-.1	+.3	-.05	+.3	-.1
11W1	+.1	-.1	+.05	-.05	0	-.2	+.05	-.05	+.05	-.05	+.05	-.1
11W2	+.1	-.1	+.05	-.05	0	-.1	+.05	-.05	+.05	-.05	+.05	-.05
11W3	+.2	-.2	+.15	-.1	0	-.2	+.1	-.1	+.05	-.2	+.1	-.15
11W4	+.2	-.1	+.05	-.05	+.05	-.1	+.05	0	+.05	-.1	+.1	-.05
11W5	+.1	-.1	+.05	-.05	+.1	-.05	+.05	0	+.05	-.1	+.05	-.05
15NW	+.1	-.25	+.05	-.1	+.1	-.15	+.1	-.4	+.05	-.3	+.1	-.25

Table 2

Pressure coefficients for S winds

(based on corresponding wind speeds at Kingsway)

	Normal Gusts						Extreme Gusts					
	9.3.63 13.35		9.3.63 15.35		Mean		9.3.63 13.35		9.3.63 15.35		Mean	
15E3	0	-.35	0	-.25	0	-.3	0	-.3	0	-.35	0	-.35
11E1	+.05	-.3	0	-.2	+.05	-.25	+.1	-.3	0	-.2	+.05	-.25
11E2	0	-.3	0	-.25	0	-.25	+.1	-.3	0	-.25	+.05	-.3
11E3	0	-.2	0	-.15	0	-.15	+.05	-.2	+.05	-.2	+.05	-.2
11E4	+.05	-.3	+.05	-.2	+.05	-.25	+.1	-.3	+.1	-.2	+.1	-.25
11E5	+.1	-.35	+.05	-.2	+.1	-.3	+.1	-.3	+.1	-.25	+.1	-.3
11W1	+.05	-.55	+.1	-.5	+.1	-.55	+.05	-.55	+.4	-.55	+.25	-.55
11W2	+.15	-.6	+.3	-.4	+.2	-.5	+.3	-.6	+.4	-.4	+.35	-.5
11W3	+.2	-.35	+.2	-.25	+.2	-.3	+.25	-.35	+.3	-.2	+.3	-.3
11W4	+.1	-.15	+.2	-.1	+.15	-.15	+.1	-.15	+.25	-.1	+.2	-.15
11W5	+.1	-.15	+.1	-.1	+.1	-.15	+.1	-.15	+.15	-.1	+.15	-.15
15W4	+.05	-.1	+.05	-.05	+.05	-.1	+.1	-.15	+.05	-.1	+.1	-.15

pattern has a general similarity to, but some differences from, the patterns obtained in wind-tunnel experiments on a model of comparable shape[5]. In view, however, of the very low values of the coefficients realized on the west, the leeward face, during NE winds, there must still be doubt about the suitability of the room pressure as a datum, and a possible error due to this cause must be borne in mind in attempting to utilize these results.

Another feature of the wind effect that has been abstracted from some of the records of NE winds analysed in appendix C is a relationship between the peak pressure exerted at a point on the structure and the time for which it acts. Samples of these results are given in *Table 3*, in each case taken from gauge 11E2, which showed a maximum effect under these winds.

Table 3

Duration of gust (secs.)	Mean Pressure lb/ft^2	
	18.1.63 17.25	19.1.63 12.25
	$q(max) = 4.0$	$q(max) = 5.1$
1	2.9	3.6
2	2.8	3.3
3	2.7	3.0
5	2.5	2.8
10	2.2	2.5
60	1.1	1.6
600	0.8	0.45

These pressures rise considerably more steeply as the time interval shortens than do the corresponding figures derived from Durst's[6] gust factors. This supports the hypothesis, which can be deduced from an inspection of the wind-pressure records, that variations of pressure on the surface of a building are due more to variation of the angle at which the wind strikes the building than to variations of the speed of the wind; that is, it is the change in the angle of attack when a gust traverses a building that causes these rapid fluctuations in pressure. This effect needs to be explored further, and under a variety of wind directions and intensities.

CONCLUSIONS

The pilot experiment of wind-pressure recording at State House has indicated some of the problems to be solved before arriving at a fuller understanding of wind action on a building. Of these, the most difficult, yet most important, is the establishment of a suitable reference pressure against which the external pressures can be measured. In the experiments carried out so far at State House, high suction coefficients have been observed only in the case of surges lasting for a very few seconds, but it would be unwise to draw broad conclusions from this observation until an opportunity has come to check this effect at least on another building with a more complete gauge installation used with a more satisfactory pressure datum.

The rapidity of the pressure changes and the way they move across the faces of the building are interesting features. Positive pressures appear to build up rapidly and to act simultaneously over large parts of the surface, while the principal suction peaks, which occur with the wind at a glancing angle to the face of the building, appear to be of very short duration and to act over small parts of the surface only at any one instant. The major short duration pressure changes are linked with changes of wind direction caused by turbulence rather than by changes in the speed of the incident wind. This suggests that a new approach may be desirable in the consideration of gust factors, and that there may be important differences between the effects of the natural wind and the steady conditions used in wind-tunnel testing. A more complete investigation of this will be possible in the course of the experiments being set up at Barbican and the G.P.O. Tower.

Finally, it must be re-iterated that the work at State House is primarily exploratory and as yet incomplete. The major investigation covering tall buildings is yet to come.

ACKNOWLEDGEMENTS

A programme of this magnitude must necessarily be based on teamwork; credit in this work is due to the whole of the Instrument Section at the Building Research Station who, under the guidance of Mr. R. S. Jerrett, have carried out the preparation, installation and operation of the equipment.

Very willing co-operation has been obtained from the Meteorological Office, both in discussion of the problems of wind measurement, and in making available their records of wind at Kingsway.

The work is being carried out as part of the research programme of the Building Research Board of the D.S.I.R. and this paper is published by permission of the Director of Building Research.

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APPENDIX A

The Building Research Station's Wind-Pressure Gauge

The Building Research Station's wind-pressure gauge was designed to be mounted flush with the surface of the building to be studied and to have as large a measuring area as practicable. It therefore takes the form of a circular pressure plate, about 4 in. diameter, which is housed within an annular frame. It is supported within the frame by three double cantilever strips, as may be seen in *fig.8*. The cantilevers are flexible in a direction normal to the pressure plate but are stiff transversely so as to keep the pressure plate concentric in the frame. The narrow annular gap between the frame and the pressure plate is closed by a thin membrane of "melinex" to prevent air leakage from the front of the gauge to the inside. The dimensions of the strips are arranged so that the displacement of the pressure plate is 0.005 in. under a loading of 25 lb/ft^2, and is no more than 0.002 in. under the usual working conditions. The pressure plate is made as light as possible consistent with the requirement of adequate rigidity at the cantilever mountings, and, in consequence, the natural frequency of the gauge has been kept sufficiently high, being in excess of 50 cycles/sec.

The load on the wind-pressure gauge is measured by recording the strain in the cantilever strips by means of resistance strain gauges. Four strain gauges are attached to each strip, two on each side, so that each double-cantilever, when it deflects, puts two strain gauges into tension and the other two into compression. These are wired suitably into the four arms of a bridge circuit, and so give the maximum possible sensitivity and at the same time provide complete compensation for thermal strain in the cantilever. All three cantilevers are treated in the same manner and the corresponding strain gauges on each are connected in series in each bridge arm to ensure that each cantilever contributes its share to the output signal according to the load imposed on it.

Originally the cantilevers were made of phosphor-bronze in order to take advantage of the relatively low Young's Modulus of that material and obtain the greatest possible gauge sensitivity; but in the course of development a change was made from wire resistance gauges to foil type gauges because of their smaller physical size and it was found that the Araldite cement used with these foil gauges was unsuitable for bonding on to phosphor-bronze. Some later pressure gauges were therefore made with steel cantilevers, suitably modified in dimensions to give approximately the same sensitivity.

The gauges were calibrated by dead weight, and the calibration was confirmed by air pressure, in both positive and negative directions, and gave an output corresponding to about 40 units of strain per lb/ft^2. This, at a suitable attenuator setting in the amplifiers gives about 4 mm deflection on the recorder chart per lb/ft^2, which is the scale used in the records illustrated in this paper.

The gauges were subjected in the laboratory to extremes of temperature likely to be encountered in service and the effects were found to be negligible. Some difficulties were, however, encountered when the gauges were put into service, some of them showing excessive zero drift. This was traced mainly to creep in the metal of the gauge bodies following the machining operation. It has been much reduced by careful selection of the material of which the gauges are now made, and by appropriate treatment, but it led to a trial of a further variant of the cantilever system which appears to be successful in minimizing the effects of strain in the bodies. This was to substitute simple cantilevers for the double ones, each cantilever being fixed rigidly to the frame of the gauge but having a universal pivot connection to the pressure plate. This improvement is achieved at the cost of some increase in the complexity of the manufacturing process and the method is only used if the rigid mounting proves troublesome.

APPENDIX B

<u>Survey of Internal Pressures in State House</u>

Condition	Strong westerly wind	- 8th August, 1961
	typical gusts 41 m.p.h.	$q = 4.2$ lb/ft^2
	max. gusts 44 m.p.h.	$q = 4.8$ lb/ft^2

Readings were taken with an aneroid barometer at various positions in the building, with various conditions of window and door openings. All barometer stations were at sill height to enable comparisons to be made. Since the barometric pressure was itself rising by 0.085 cm/hour during the course of the survey, all readings have, for the purposes of comparison, been adjusted to a common point in time. They have also been adjusted to a common height above ground, according to the relationship, for a standard atmosphere, that 100 ft of height corresponds to a pressure difference of 0.272 cm of mercury. The correction per storey height, which is 10.1 feet, is thus 0.02745 cm.

The reference point is taken as 15.15 hrs at 14th floor level, and results are tabulated overleaf.

The aneroid used for this survey had a scale marked in divisions of 0.1 cm and it was necessary to judge the second decimal place by eye and to take great care to avoid parallax errors. It will therefore be seen that the instrument was barely adequate to deal with the small variations of pressure within the building, and too much reliance should not be placed on the last digit. There is, however, a fairly general agreement that the interior pressure was 75.32 ± 0.01 (adjusted to the level of the 14th floor) when windows were closed: that it varied by very little when east face windows were opened: but that when windows were opened on the windward side there were variations of pressure amounting to about 0.15 cm, that is 4.2 lb/ft^2, during gusts, at a time when the maximum dynamic pressure head of the measured gusts was 4.8 lb/ft^2.

Time	Location ref. fig. 1	Floor level	Conditions	Readings and adjustments	Adjusted values
14.40	A	Ground	interior space windows closed door open	75.63 time correction + 0.05 height " - 0.38 total " - 0.33	75.30
14.55	B	15	lift vestibule (ventilated)	75.25 time correction + 0.03 height " + 0.03 total " + 0.06	75.31
15.00	C	15	by open window east side	75.26 time correction + 0.02 height " + 0.03 total " + 0.05	75.31
15.05	D	15	west side room window closed door open	75.28 (.26)* (.29) time correction + 0.01 height " + 0.03 + 0.04	75.32 (.30)* (.33)
			window open door closed	75.31 (.29)* (.37)	75.35 (.33)* (.41)

Time	Location ref. fig.1	Floor level	Conditions	Readings and adjustments	Adjusted values
15.15	E	14	lift vestibule (ventilated)	75.33(steady)	75.33
	F	14	SE corner room window open door closed	75.33(steady)	75.33
15.20	G	14	SW corner room window closed door open	75.32	75.32
			window open door closed	75.36 (.35)* (.50)	75.36 (.35)* (.50)
	H	14	NW corner room window closed door open	75.33	75.33
			west face window open door closed	75.39 (.36)* (.48)	75.39 (.36)* (.48)

* range in gusts

APPENDIX C

Analysis of wind pressure records

Record from 18.1.63 : 17.25 hrs.
mean wind direction NE (55°)
range 350° to 90°

mean wind speed	20 m.p.h.	$q = 1.1\ lb/ft^2$
frequent gusts to	34 m.p.h.	$q = 2.9\ lb/ft^2$
max. gusts to	40 m.p.h.	$q = 4.0\ lb/ft^2$

Gauge	Mean wind		Normal gusts				Extreme gusts			
	press. lb/ft^2	coeff.	press. range lb/ft^2		coeff.		press. range lb/ft^2		coeff.	
15E3	1.0	.9	2.5	0	.85	0	2.9	-.7	.75	-.2
11E1	.45	.4	1.9	-.9	.65	-.3	2.7	-1.1	.7	-.25
11E2	.8	.7	2.2	-.9	.75	-.3	3.0	-1.35	.75	-.35
11E3	1.0	.9	2.5	0	.85	0	2.9	-.55	.75	-.15
11E4	.35	.3	1.35	-.2	.45	-.1	1.6	-.45	.4	-.1
11E5	.35	.3	1.1	0	.35	0	1.5	-.2	.4	-.05
11W1	-.1	-.1	.2	-.2	.1	-.1	.35	-.35	.1	-.1
11W2	-.1	-.1	.2	-.35	.1	-.1	.35	-.35	.1	-.1
11W3	-.2	-.2	.55	-.55	.2	-.2	.8	-.8	.2	-.2
11W4	-.2	-.2	.35	-.35	.1	-.1	.7	-.45	.2	-.1
11W5	0	0	.2	-.2	.1	-.1	.35	-.35	.1	-.1
15NW			.2	-.45	.1	-.15	.45	-.10	.1	-.25

Record from 18.1.63 : 19.25 hrs.
Mean wind direction NE (55°)
Range 20° to 90°

mean wind speed	29 m.p.h.	$q = 2.2\ lb/ft^2$
frequent gusts to	37 m.p.h.	$q = 3.6\ lb/ft^2$
max. gusts to	44 m.p.h.	$q = 4.9\ lb/ft^2$

Gauge	Mean wind		Normal gusts				Extreme gusts			
	press. lb/ft^2	coeff.	press. range lb/ft^2		coeff.		press. range lb/ft^2		coeff.	
15E3	.45	.2	1.6	0	.45	0	1.9	-.2	.4	-.05
11E1	.1	.05	1.0	-.7	.3	-.2	1.9	-.9	.4	-.2
11E2	.45	.2	1.5	-.7	.4	-.2	2.4	-2.0	.5	-.4
11E3	.55	.25	1.35	0	.35	0	2.1	-.45	.4	-.1
11E4	.1	.05	1.0	-.2	.3	-.05	1.35	-.35	.25	-.05
11E5	.1	.05	.7	-.2	.2	-.05	.8	-.45	.15	-.1
11W1	-.1	.05	.2	-.2	.05	-.05	.35	-.2	.05	-.05
11W2	-.1	.05	0	-.2	0	-.05	.2	-.2	.05	-.05
11W3	-.1	.05	.45	-.45	.1	-.1	.8	-.45	.15	-.1
11W4	-.1	.05	0	-.2	0	-.05	.35	-.2	.05	-.05
11W5	0	0	.2	0	.05	0	.35	-.2	.05	-.05
15NW	0	0	.2	-.55	.05	-.15	.2	-.55	.05	-.1

Record from 18.1.63 : 20.25 hrs.
Mean wind direction NE (55°)
Range 20° to 95°

mean wind speed	19 m.p.h.	q = 1.0 lb/ft^2
frequent gusts to	32 m.p.h.	q = 2.6 lb/ft^2
max. gusts to	36 m.p.h.	q = 3.1 lb/ft^2

Gauge	Mean wind		Normal gusts				Extreme gusts			
	press. lb/ft^2	coeff.	press. range lb/ft^2		coeff.		press. range lb/ft^2		coeff.	
15E3	.65	.65	1.6	-.1	.6	-.05	1.9	-.45	.6	-.15
11E1	.2	.2	1.0	-1.35	.4	-.5	1.8	-1.8	.6	-.6
11E2	.55	.55	1.6	-.8	.6	-.3	2.2	-1.1	.7	-.35
11E3	.65	.65	1.5	0	.6	0	2.1	-.45	.7	-.15
11E4	.1	.1	.9	-.45	.35	-.15	1.0	-.65	.3	-.2
11E5	.1	.1	.8	-.45	.3	-.15	.9	-.8	.3	-.25
11W1	-.1	-.1	0	-.45	0	-.15	0	-.55	0	-.2
11W2	-.1	-.1	0	-.2	0	-.1	0	-.35	0	-.1
11W3	-.2	-.2	0	-.55	0	-.2	0	-.7	0	-.2
11W4	-.1	-.1	0	-.35	0	-.15	.1	-.35	.05	-.1
11W5	0	0	.2	-.1	.1	-.05	.35	-.2	.1	-.05
15NW	0	0	.2	-.45	.1	-.15	.35	-.45	.1	-.15

Record from 19.1.63 : 12.25 hrs.
Mean wind direction NE (45°)
Range 330° to 100°

mean wind speed	23 m.p.h.	$q = 1.4$ lb/ft^2
frequent gusts to	42 m.p.h.	$q = 4.4$ lb/ft^2
max. gusts to	46 m.p.h.	$q = 5.1$ lb/ft^2

Gauge	Mean wind		Normal gusts				Extreme gusts			
	press. lb/ft^2	coeff.	press. range lb/ft^2		coeff.		press. range lb/ft^2		coeff.	
15E3	.65	.45	1.8	-.45	.4	-.1	3.6	-1.8	.7	-.35
11E1	.2	.15	1.8	-1.35	.4	-.3	3.3	-1.6	.65	-.3
11E2	.45	.3	1.6	-1.1	.35	-.25	3.8	-2.2	.75	-.45
11E3	.35	.25	1.1	-.65	.25	-.15	2.7	-1.8	.55	-.35
11E4	.2	.15	.9	-.55	.2	-.15	2.1	-1.35	.4	-.25
11E5	.2	.15	.55	-.2	.15	-.05	1.35	-.55	.25	-.1
11W1	0	0	.1	-.2	0	-.05	.2	-.35	.05	-.05
11W2	0	0	.1	-.2	0	-.05	.2	-.35	.05	-.05
11W3	.1	.05	.2	-.35	.05	-.05	.65	-.45	.1	-.1
11W4	.1	.05	.35	-.1	.05	0	.35	-.1	.05	0
11W5	.1	.05	.35	0	.05	0	.35	-.1	.05	0
15NW	0	0	.35	-.55	.05	-.15	.45	-2.0	.1	-.4

Record from 19.1.63 : 13.25 hrs.
Mean wind direction NE then SE (40° then 120°)
Range 350° to 90° then 85° to 220° (SW)

mean wind speed	possibly 23 m.p.h. (difficult to assess)	$q = 1.4$ lb/ft^2
frequent gusts to	46 m.p.h.	$q = 5.1$ lb/ft^2
max. gusts to	51 m.p.h.	$q = 6.5$ lb/ft^2

Gauge	Mean wind		Normal gusts				Extreme gusts			
	press. lb/ft^2	coeff.	press. range lb/ft^2		coeff.		press. range lb/ft^2		coeff.	
15E3	1.1	.8	2.9	0	.55	0	3.8	-2.0	.6	-.3
11E1	.1	.1	2.0	-1.6	.4	-.3	3.8	-1.8	.6	-.3
11E2	.8	.55	2.5	-1.6	.5	-.3	3.8	-2.0	.6	-.3
11E3	.8	.55	2.6	0	.5	0	3.6	-1.35	.55	-.2
11E4	.45	.3	1.6	-.45	.3	-.1	2.1	-1.0	.35	-.15
11E5	.45	.3	1.5	0	.3	0	2.0	-.35	.3	-.05
11W1	-.2	-.15	0	-.45	0	-.1	.2	-.55	.05	-.05
11W2	-.1	-.1	.1	-.2	0	-.05	.2	-.35	.05	-.05
11W3	-.35	-.25	.2	-.9	.05	-.2	.35	-1.35	.05	-.2
11W4	-.35	-.25	0	-.7	0	-.15	.2	-.7	.05	-.1
11W5	0	0	.35	-.35	.05	-.05	.35	-.7	.05	-.1
15NW			.2	-1.2	.05	-.25	.45	-2.0	.05	-.3

Record from 9.3.63 : 13.35 hrs.
Mean wind direction S (190°)
Range 120° to 270°

mean wind speed	23 m.p.h.	$q = 1.4$ lb/ft^2
frequent gusts to	44 m.p.h.	$q = 4.9$ lb/ft^2
max. gusts to	51 m.p.h.	$q = 6.5$ lb/ft^2

Gauge	Mean wind		Normal gusts				Extreme gusts			
	press. lb/ft^2	coeff.	press. range lb/ft^2		coeff.		press. range lb/ft^2		coeff.	
15E3	-.8	-.55	-.1	-1.6	0	-.35	0	-2.1	0	-.3
11E1	-.2	-.15	+.2	-1.35	+.05	-.3	+.8	-1.9	+.1	-.3
11E2	-.8	-.55	0	-1.45	0	-.3	+.7	-2.0	+.1	-.3
11E3	-.35	-.25	+.1	-1.0	0	-.2	+.2	-1.25	+.05	-.2
11E4	-.55	-.4	+.2	-1.45	+.05	-.3	+.55	-1.9	+.1	-.3
11E5	-.55	-.4	+.45	-1.8	+.1	-.35	+.8	-2.0	+.1	-.3
11W1	-.9	-.65	+.2	-2.7	+.05	-.55	+.45	-3.6	+.05	-.55
11W2	-.45	-.3	+.7	-2.9	+.15	-.6	+1.9	-3.8	+.3	-.6
11W3	-.2	-.15	+1.0	-1.7	+.2	-.35	+1.7	-2.2	+.25	-.35
11W4	0	0	+.45	-.8	+.1	-.15	+.55	-1.1	+.1	-.15
11W5	0	0	+.45	-.7	+.1	-.15	+.55	-.9	+.1	-.15
15W4	-.1	-.05	+.35	-.55	+.05	-.1	+.55	-.8	+.1	-.15

Record from 9.3.63 : 15.35 hrs.
Mean wind direction S (180°)
Range 90° to 240°

mean wind speed	23 m.p.h.	q = 1.4 lb/ft^2
frequent gusts to	39 m.p.h.	q = 3.9 lb/ft^2
max. gusts to	45 m.p.h.	q = 5.0 lb/ft^2

Gauge	Mean wind		Normal gusts				Extreme gusts			
	press. lb/ft^2	coeff.	press. range lb/ft^2		coeff.		press. range lb/ft^2		coeff.	
15E3	-.45	-.3	+.1	-.9	0	-.25	+.1	-1.8	0	-.35
11E1	-.1	-.05	+.1	-.8	0	-.2	+.1	-1.0	0	-.2
11E2	-.35	-.25	0	-.9	0	-.25	+.1	-1.35	0	-.25
11E3	-.2	-.15	0	-.55	0	-.15	+.2	-1.0	+.05	-.2
11E4	-.2	-.15	+.2	-.8	+.05	-.2	+.45	-.9	+.1	-.2
11E5	-.1	-.05	+.2	-.8	+.05	-.2	+.55	-1.25	+.1	-.25
11W1	-.55	-.4	+.35	-2.0	+.1	-.5	+2.1	-2.7	+.4	-.55
11W2	0	0	+1.1	-1.5	+.3	-.4	+1.9	-1.9	+.4	-.4
11W3	0	0	+.8	-.9	+.2	-.25	+1.6	-1.0	+.3	-.2
11W4	0	0	+.7	-.45	+.2	-.1	+1.25	-.55	+.25	-.1
11W5	0	0	+.45	-.45	+.1	-.1	+.7	-.55	+.15	-.1
15W4	0	0	+.2	-.2	+.05	-.05	+.35	-.55	+.05	-.1

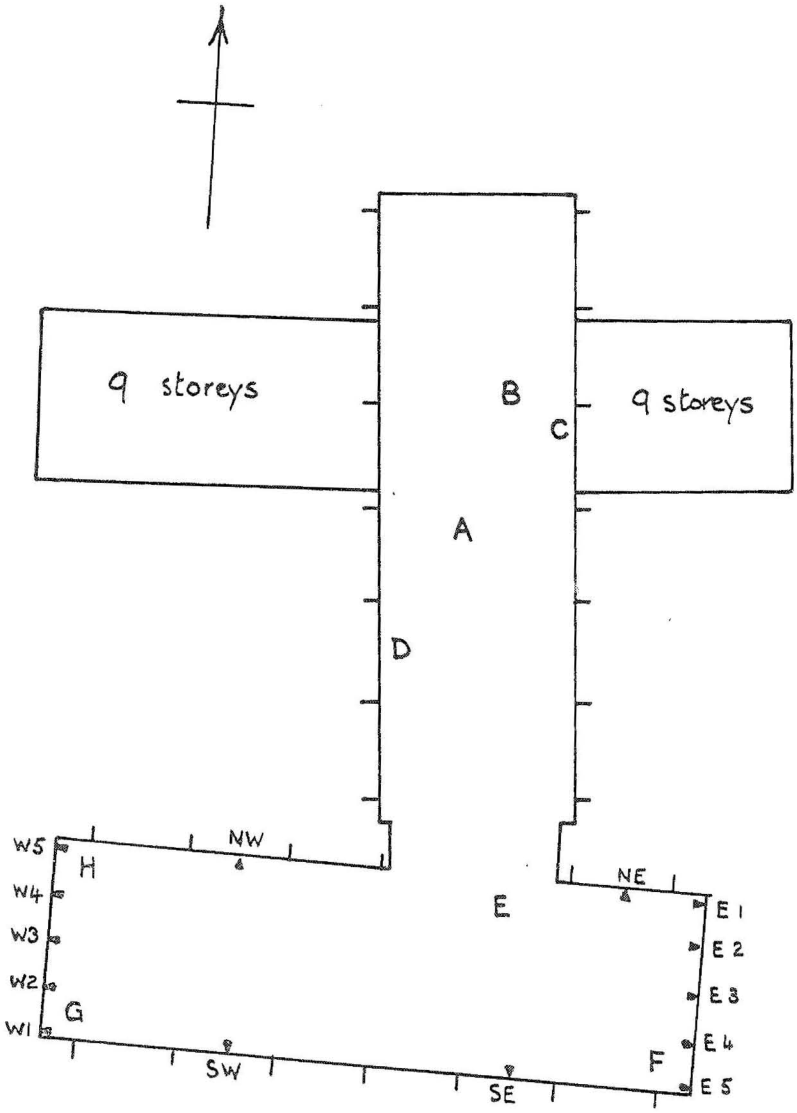

Fig. 1. Plan of State House showing gauge positions.

Fig.2. Part of State House from the south-west.

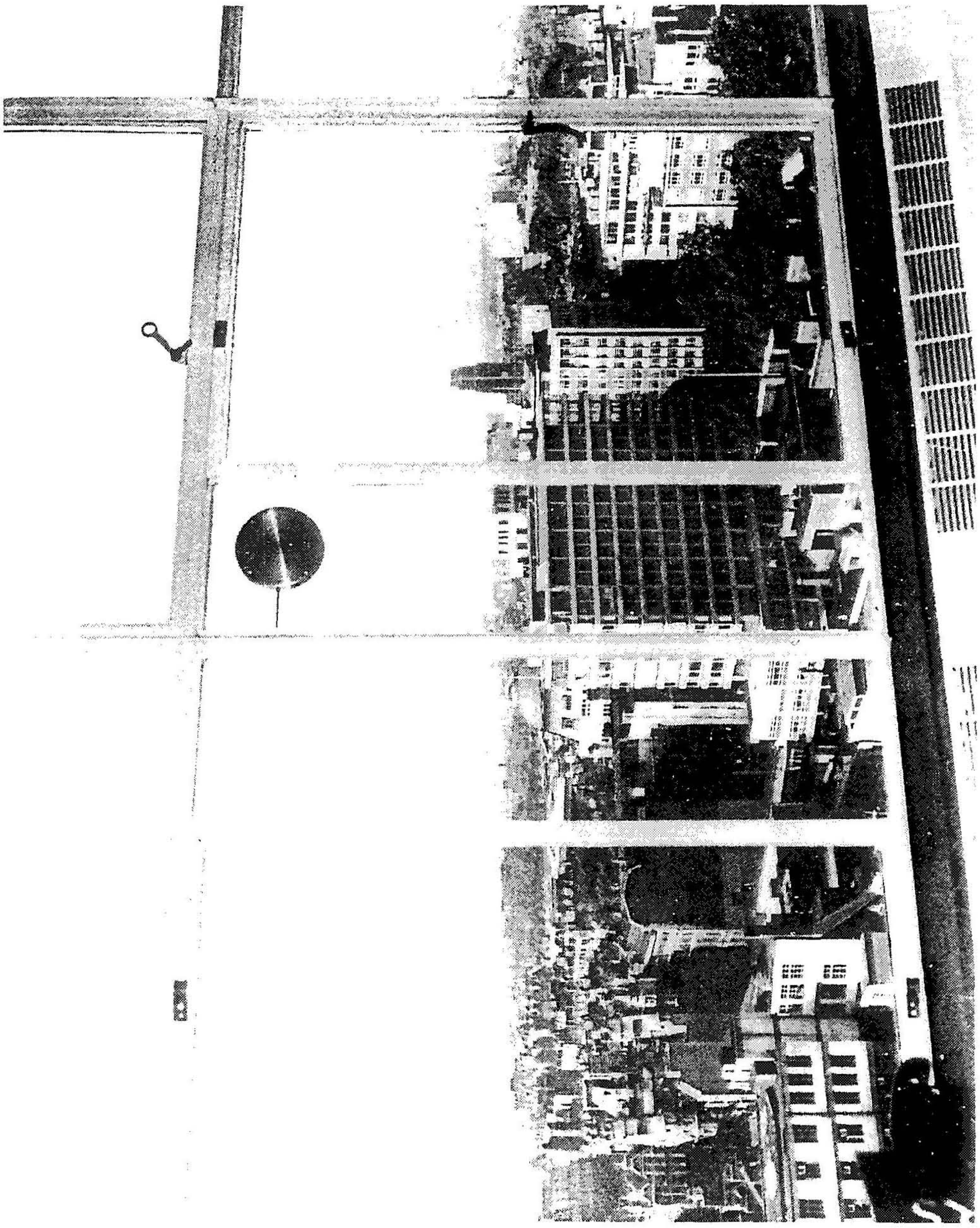

Fig. 3. Wind-pressure gauge in 15th floor window of State House.

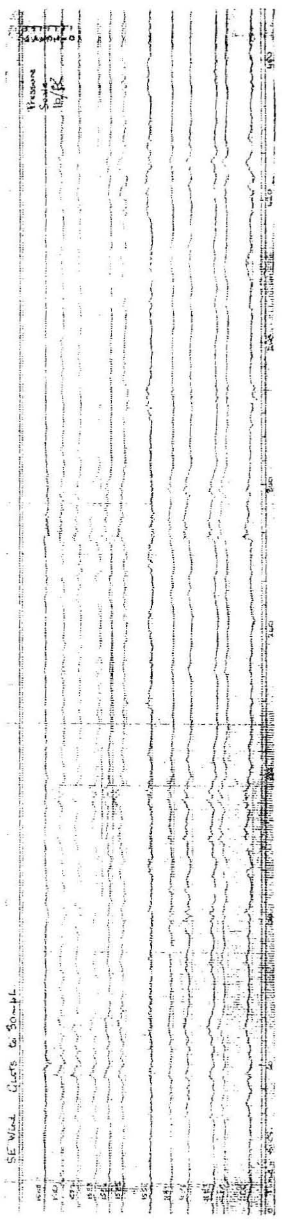

Fig.4.

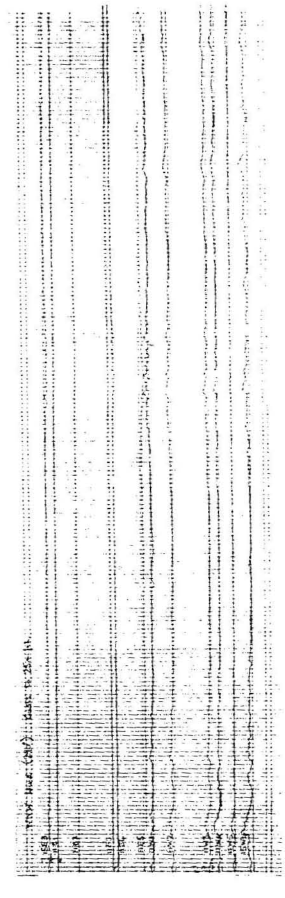

Fig.5.

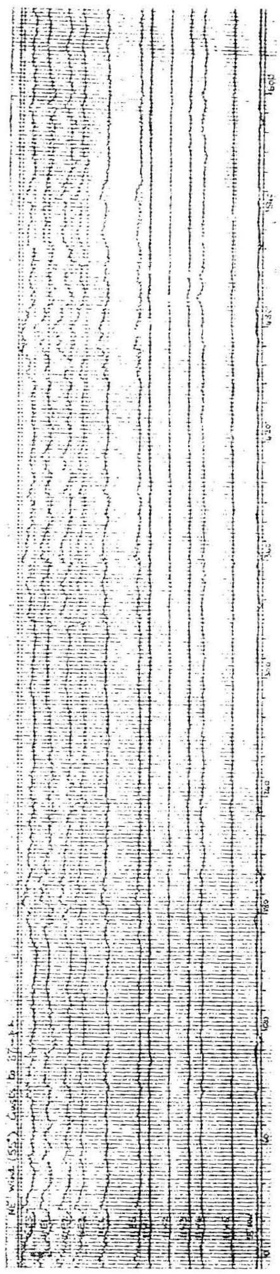

Fig.6.

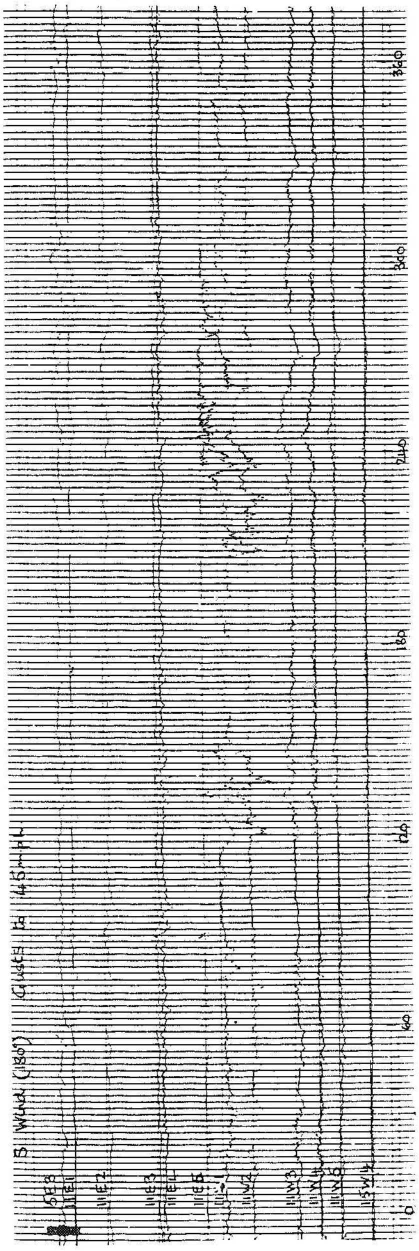

Fig. 7a.

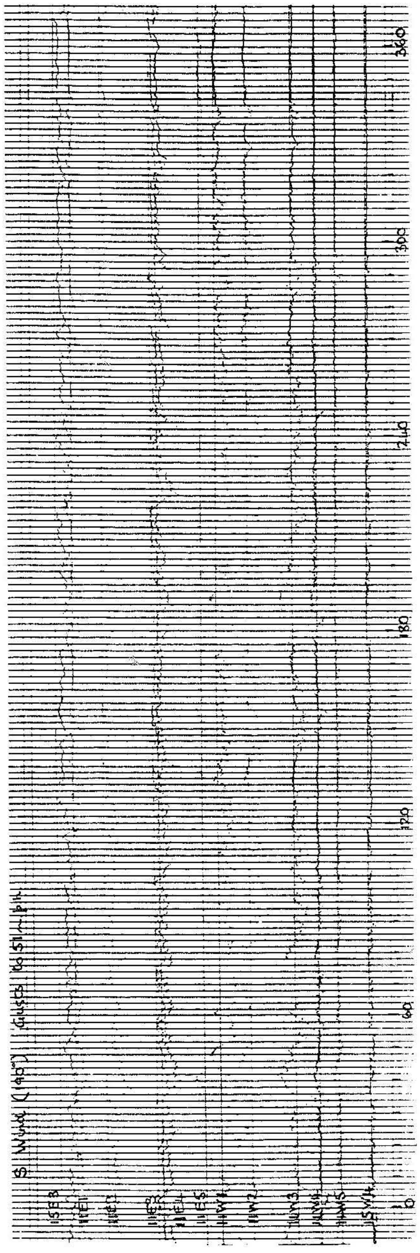

Fig. 7b.

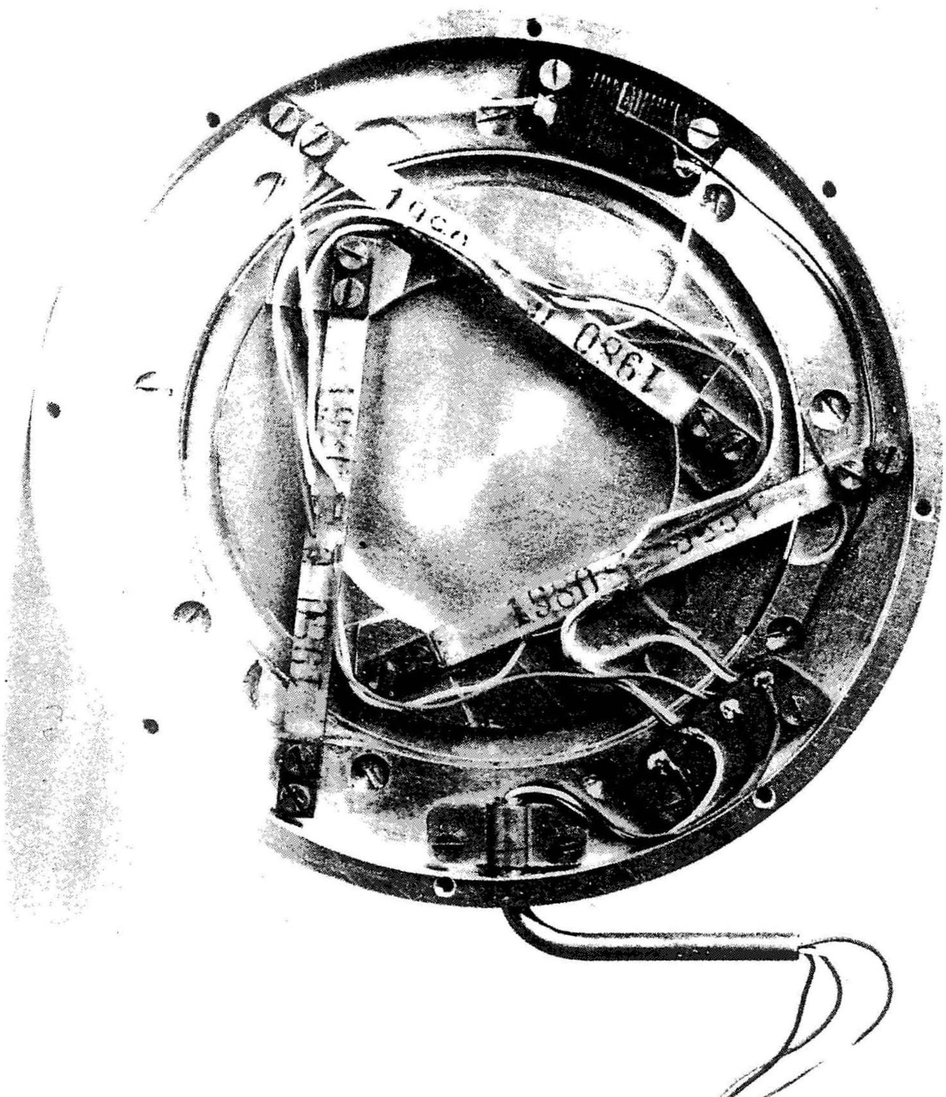

Fig. 8. Rear view of wind-pressure gauge with back cover removed.

DISCUSSION ON PAPER 13

PROFESSOR PAGE mentioned a theory which had been developed for ventilation problems which enabled the internal pressure of a building to be calculated. This theory uses an electric circuit analogy. He suggested that the theory could be developed to determine the build up of internal pressure in gusting winds.

MR. ROWE mentioned the similarity between gusting winds and air blasts and some experiments he had carried out with a shock wave passing over elementary building forms. With regard to the problem of a reference pressure in measurements on buildings he thought that the best solution was to take absolute pressures and relate them at the same time to the common reservoir pressure and to the pressure inside the room itself.

MR. RIMMER enquired whether the distortion of the window frame under wind would alter the accuracy of the gauge.

MR. NEWBERRY (in reply) doubted whether the electrical analogy mentioned by Professor Page was sufficient for the purpose of the measurements he had undertaken. He thought also that the analogy with blasts suggested by Mr. Rowe might be dangerous because of the evident fundamental differences between the two flow régimes. In reply to Mr. Rimmer he said that the gauges had been designed to keep acceleration effects to a minimum and neither acceleration effects nor distortion of the frame interfered with the accuracy of the gauge in its present use.