The Effect of Building Grouping on Wind Induced Natural Ventilation

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SUMMARY

To obtain accurate estimates of wind induced natural ventilation of buildings the pressure distribution over the building is required. Such information is sometimes available for isolated buildings but is very rarely available for groups of buildings.

A review of available information is given together with the results of measurement made on a cuboid when surrounded by buildings of the same shape. The results which are presented statistically indicate that the pressure distribution on a building can be fairly accurately determined provided the density of the built form and the roughness fetch is known.

1. Introduction

One of the major difficulties [1] encountered in estimating ventilation and infiltration rates in buildings is the availability of wind pressure distributions on the buildings. The present work was undertaken in an attempt to provide such data, without the designer having recourse to wind tunnel studies.

There are two main limitations of the existing pressure distribution information:

i) it is for a limited number of building shapes, and

ii) the pressure distributions are almost invariably for isolated buildings; a situation that is rarely encountered.

A brief mention of work done on predicting pressures on bluff bodies of any shape will be made but the main emphasis in this paper will be on a statistical approach to the prediction of pressures on a bluff body in a shear layer and in the presence of other bluff bodies of a similar shape, a situation which is representative of many urban and suburban areas.

The statistical approach to this problem seems the only realistic one as the number of variables involved in studies in groups of more than two buildings is so large that a definitive approach is not possible (see for example [2]). Even though the parameters, studied by Wise in his two building cases, were varied over a large range, the work remains too specific to be of much assistance to a designer. At the other extreme the work of Sutton [3] and Davenport [4] in defining the flow over large urban areas is too general and too inaccurate at roof top levels and below to be useful in predicting pressure distributions. In between these extremes there is a surprising paucity of information.

In the present case the bluff bodies were identical in form (cuboids) but in future work it is hoped to extend the work to different shapes and sizes. Pressure differences and confidence limits have been obtained for various building group patterns, building densities and areas of built form.

Information has also been obtained on the influence of surrounding buildings and the area which needs to be modelled if accurate results are to be obtained (approximately five building blocks is usually assumed to be sufficient [5]) which should be of interest to those concerned with wind tunnel modelling.

2. Natural Ventilation

Some ventilation is necessary in most types of buildings in order to maintain comfortable conditions for human occupation. Replacement of air is required for three reasons:

i) to provide adequate oxygen for the occupants

ii) to remove products of occupation e.g. odours, gases, vapours (especially water vapour) and solid particles, and

iii) to assist in controlling the thermal conditions in the space e.g. remove heat and generate air movement.

Infiltration, which is unintentional ventilation or air leakage, may not be harmful in some situations, but in Britain, where it has been estimated that half the heat lost by buildings in winter is through ventilation and infiltration, it is particularly important to accurately assess ventilation and infiltration rates.

There are a number of mechanisms which produce ventilation, e.g.

i) Wind forces

ii) Buoyancy forces

iii) Turbulent diffusion (caused by unsteady wind or buoyancy forces or building occupancy), and

iv) Molecular diffusion.

In the present work only steady wind forces are considered.

There are two common methods in use for estimating ventilation and infiltration rates; the crack method and the air change method [6]. The main point to be made here is that neither approach takes into account the sheltering effect of nearby building quantitatively. Nelson [7] has suggested a certain correction for nearby buildings but the correction appears to be based on the two-building case of Vincent and Bailey [8].

3. Flow in Transitional Zones

There are two main sources of information of direct relevance to the present work:

i) Flow in a boundary layer over a rough surface (a building represents a roughness element), and

ii) Flow over specific groups of buildings.

The boundary layer flow literature appears to be of great use but in the case of a building in an urban setting the flow is usually readjusting itself to a new set of boundary conditions (transition zone) which limits even further the limited amount of relevant literature.

3.1 Flow Over Roughness Elements in a Boundary Layer

In Figure 1 a schematic presentation of the velocity profile in an urban area [9] is presented. It shows two distinct sublayers within the boundary layer; the surface roughness layer (zone A) and the interfacial layer (zones B and C). The flow over the roughness produces an effective ground level displacement, d.

At a step change of surface roughness a new internal boundary layer begins to form and gradually thickens. Figure 2 shows the change in the velocity profile at a step change in surface roughness, from a smooth to a rough boundary. Although very long fetches are required to achieve stability throughout the full depth of the boundary layer very short fetches only are needed to achieve stability at lower heights [4] [10].

Apart from the work done by Joubert et al [11] no pressure measurements have been published on three dimensional roughness elements. Much more information exists on pressure distributions over two dimensional roughness elements [11] [12] [13]. Pressure distributions in cut-outs [14] and behind a step [15] are also of interest.

To obtain an understanding of the flow over three dimensional roughness elements information on velocities within the roughness height is necessary [16] [17] [18]. On the basis of the work on two-dimensional roughness, the flow over roughness elements can be classified into two groups:

i) "d" type roughness if the spacing between the roughness elements, s, is less than or equal to the roughness height, h, and

ii) "k" type roughness if s is greater than h.

Stable vortices are formed in the grooves in "d" type roughness and velocity gradients below the roughness height are not related to the incident flow. With "d" type roughness the distance of the apparent ground plane $\varepsilon(= h - d - z_0)$ is proportional to the roughness fetch x and the internal layer depth, δ_i. It was also found that ith this roughness type the drag (and hence pressure distribution) on any element is critically dependent on the alignment of the elements.

With "k" type roughness ε is proportional to the elemental roughness height, h, while the drag is no longer sensitive to small variation in h.

Figure 3 shows the pressure distribution over a "d" type roughness element [12] and Figure 4 shows the pressure distribution over a "k" type element [13]. In both cases the leeward pressure remained almost constant over the element height.

The "d" type pressure distribution results have a form very similar to those obtained for flow over grooves (see Figure 5). It would seem then that the flow "sees" the roughness elements as grooves rather than projections in this case.

A preliminary investigation of three dimensional roughness elements [11] showed that the drag varies with both the frontal aspect ratio, A, and δ/h. Counihan [16] found that the roughness length z_o increased with the area density, regardless of pattern, and reached a maximum value at an area density of 25%. The zero plane displacement, d, increased with an increase in density (see Figure 6).

Beddingfield et al [17] investigated the flow entering an array of cubes having spacings of h/2, h and 1.5 h. He noted that for arrays when the spacing between cubes was h/2 and h, flow stability was mostly obtained after the fourth "cell" on the street centre line, and after the third "cell", on the centre line of the cubes. In the 1.5 h array the velocities decrease until the fourth cell and then increase slightly. The significance of this work will be explained in the following section.

3.2 Specific Building Groupings

Apart from the BRS work [2] and that of Vincent and Bailey [8], most building groupings studied have been specific ones, in order to study structural or environmental wind loadings on a proposed building.

4. The Wind Tunnel Model

The wind tunnel model was a grouping of 2 cm. cubes with a fetch of up to 15 h. This may seem a very specific case but there are some points which make it more general than it might first appear; these are the type of roughness and the similarity of flow over isolated roughness elements and the length of fetch.

4.1 Type of Roughness

As already mentioned the flow over "k" type roughness is virtually unaffected by small changes in the roughness element height [11]. In the present work and in urban environments we are mostly dealing with "k" type roughness.

4.2 Flow Similarity

Smith [19] and Evans [20] carried out wind tunnel studies on the flow behind various shapes and sizes of isolated buildings. It was found by re-analysing and plotting Evans results non-dimensionally (E/H against L/H) that 90% of the results were within ± 33% limits of a mean curve, where E is the flow reattachment length, H is the model height and L is the model frontal length. If the same results are plotted using (E + W)/H instead of E/H where W is the building thickness, 90% of the points lie within ± 17.5% of the mean curve (see Figure 7).

4.3 Fetch Length

The work by Beddingfield et al, already described, shows that there is no loss of generality by considering fetch lengths as small as 10 h. Such results could equally well apply to a small development or part of a large conurbation.

4.4 Model and Experimental Facilities

The model configurations investigated were:

i) The test building to the leeward and isolated from a group of buildings, and

ii) the test building within the group of buildings.

The pattern and densities of the groupings were as shown in Figure 8.

The wind tunnel used to obtain the results in the following section was a non-return tunnel with a working section of 0.6 m by 0.6 m. The length of the working section was 2.5 m and the maximum velocity obtainable in the section was 25 m/sec.

5. Results

Two boundary layer profiles wcre used, one having a power law exponent, α, of 0.35 and a thickness, δ, of 18 cm. and the second having an exponent of 0.15 and a thickness of 5 cm.

Measurements of the pressure difference coefficient Δ Cp over the two faces of the model building were made for each grouping density, radius of built form (from the test building), boundary layer profile and for various angles of i idence of the test building and group of buildings were made.

Figure 9 shows the variation of Δ Cp on the test building when it was isolated by a distance x/h downstream of a group with an area density of 25%. It can be seen from Figure 10 that as the number of rows in the building group increases the standard deviation of the results becomes less, i.e. the prediction technique becomes more precise, and the variation in results is small for two or more rows, and as x/h increases the value of Δ Cp approaches that for the isolated case.

The work on the variation of the pressure differences coefficient on buildings within a group is more detailed and involves assessing the results of the size of the group, r/h, its density, D, and pattern, as well as the characteristics of the approaching flow and the angle of incidence of the flow.

In Figure 11 the variation of Δ Cp is plotted as a function of r/h and D. Although each built form density D, gave different results, the results showed the same trend. The group pattern(s) used are shown in Figure 8. The boundary layer with a thickness of 18 cm. was used and the flow was kept normal to the test building. Each point in Figure 11 is an average of twelve readings obtained by rotating the building group between -90° and $+90^{\circ}$ at 15° intervals. The results show that as the radius of the grouping, r/h, increases the variation in the results decreases.

The variation in pattern has different effects for different densities. Figure 12 shows a comparison between the normal pattern and the staggered pattern for 10% and 20% densities. The effect of the pattern on the 10% density results is negligible while on the 20% density it is considerable.

Approaching flow effects are shown in Figure 13. The figure shows that higher values of ΔCp are obtained in the thicker boundary layer.

Variation in values of ΔCp with angle of incidence are shown in Figure 14. Compared with the isolated building results the maximum attenuation in ΔCp was obtained for the test building normal to the flow. As the angle of incidence is increased the difference between the isolated and group ΔCp values decreases.

An investigation was also carried out on the size of the area of influence around the test building. For this part of the work it was assumed that values of ΔCp are stable if a change in the values of r/h produced a change of less than $\pm$ 5% in ΔCp. The results given in Figure 15 show a "footprint" area of influence, having its axis in the in wind direction.

6. Conclusions

From the results obtained so far it can be concluded that pressure distributions on buildings in, or at a distance from, groups could be determined fairly accurately provided the density of the built form and the roughness fetch is known. This is an important results for building ventilation estimates and is also of use in structural design though here the instantaneous pressures should be used.

The "limit of the influence" area around the building is useful in determining the correct area density of built form and it also provides a useful guide as to the area to be modelled if wind tunnel studies are to be undertaken.

This work is continuing and will be extended to investigate the effect of variations in building form and group pattern, together with small changes in building height.

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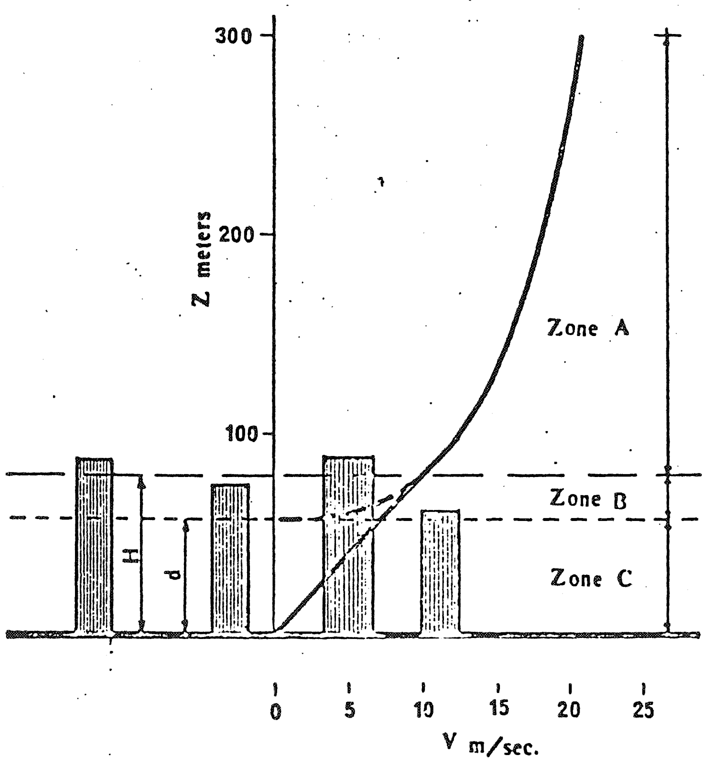


Figure 1 Air flow in built-up areas [9]

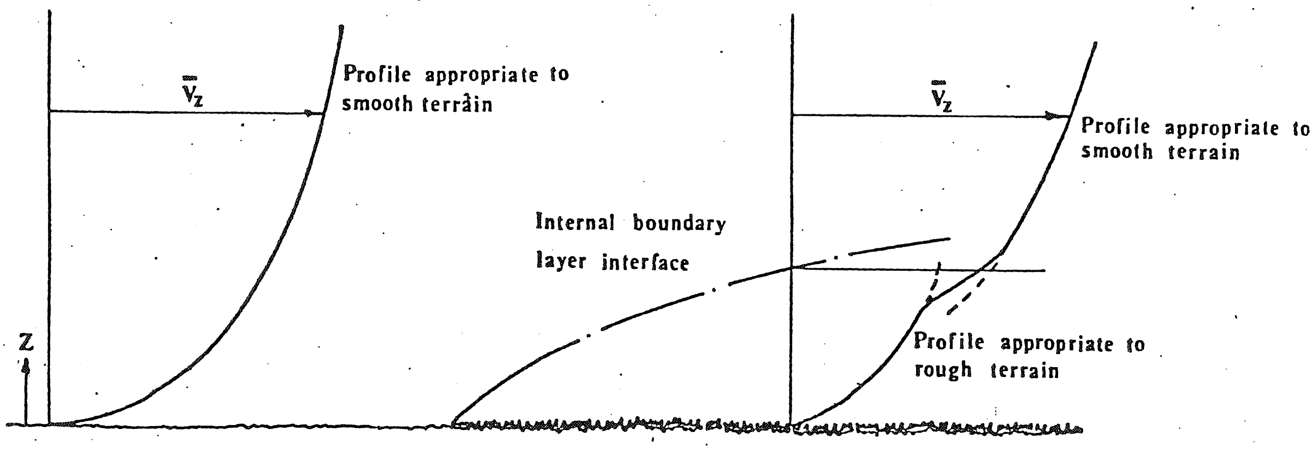
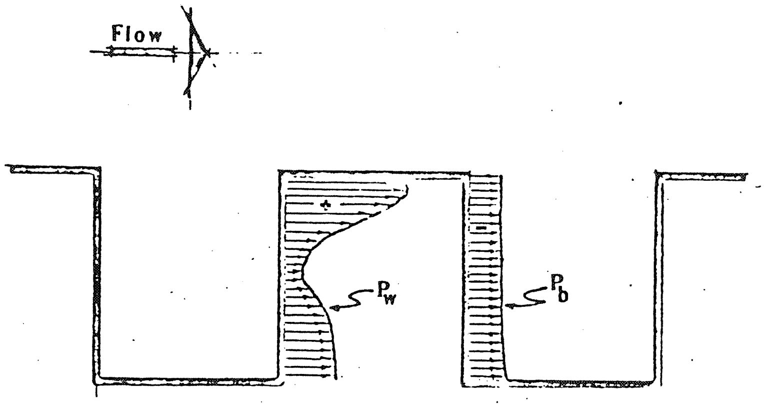


Figure 2 Schematic representation of wind passing from smooth terrain to rough terrain [21]



igure 3 Detailed pressure measurements on the windward (P_w) and leeward (P_b) faces of roughness element [12]

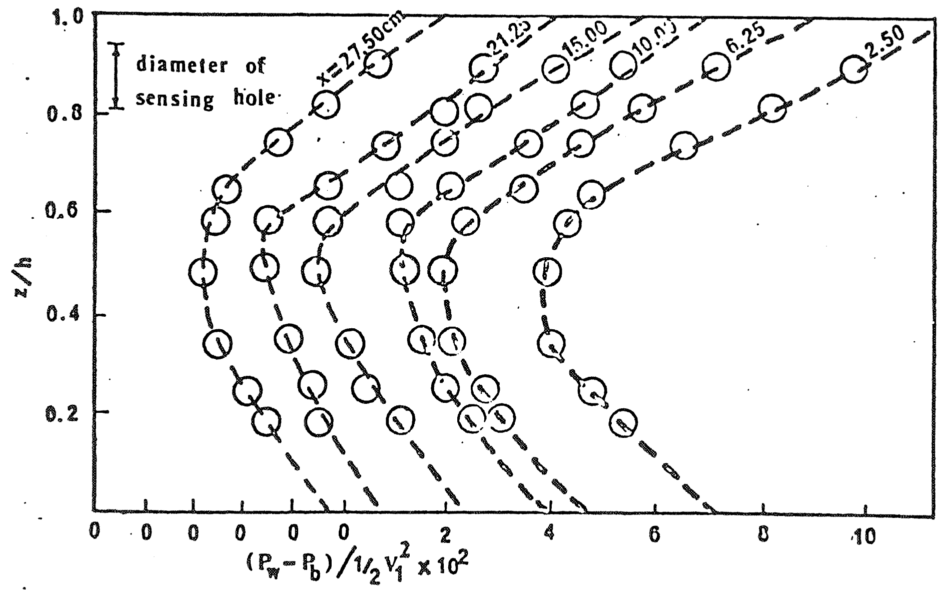


Figure 4 Pressure difference distribution along the element height, h, at small fetches (notice shift of origin) [13]

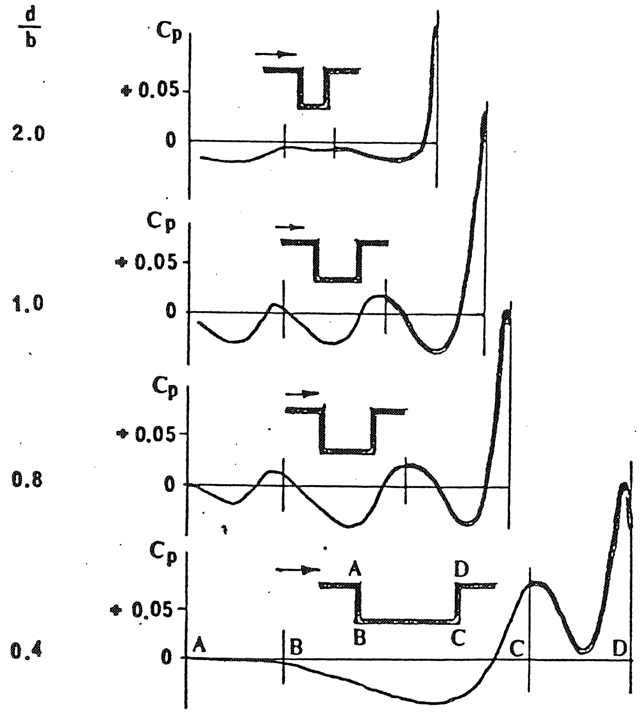


Figure 5 Pressure coefficient distribution on groove walls of various depth-breadth ratio (d/b), d = 4 cm., $V_\infty \doteq 28$ m/sec. [15]

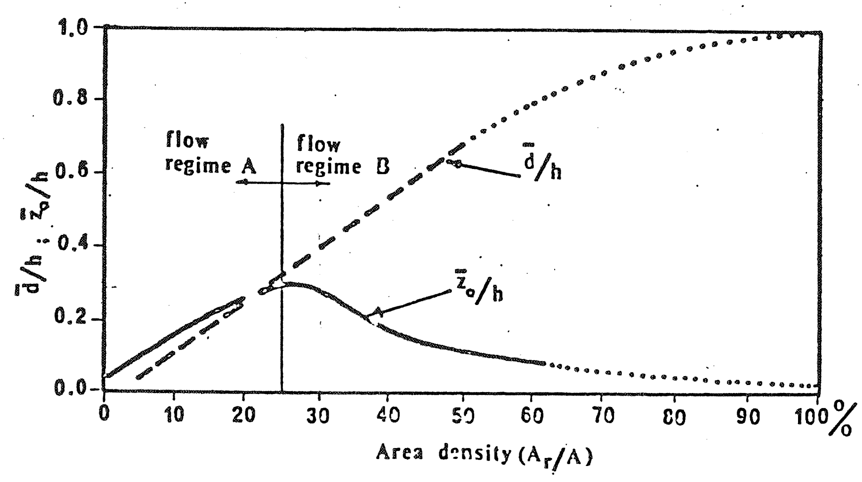
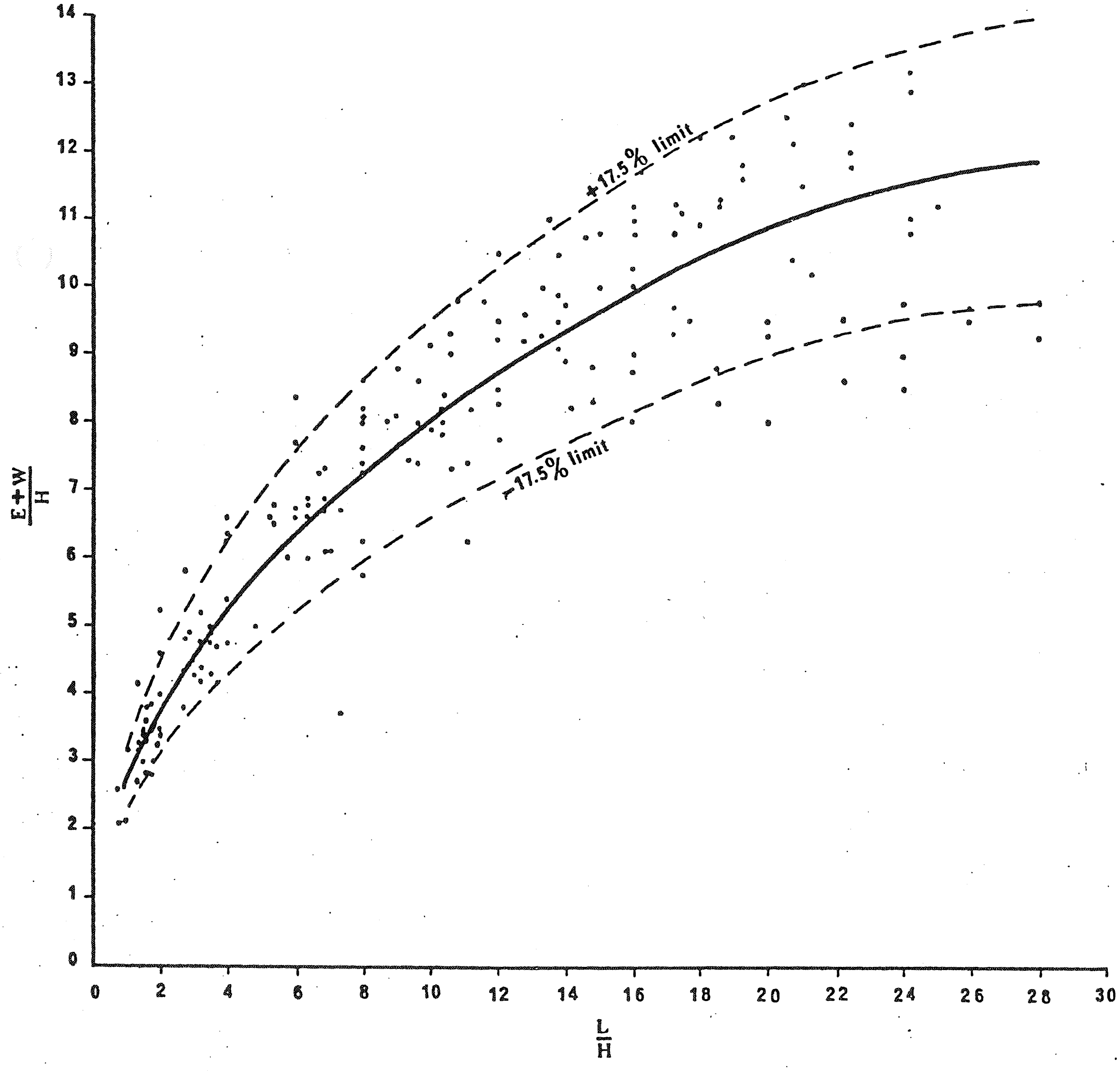


Figure 6 Variation of $\bar{z}_0/h$ and $\bar{d}/h$ with area density (Ar/A) at constant fetch [16]

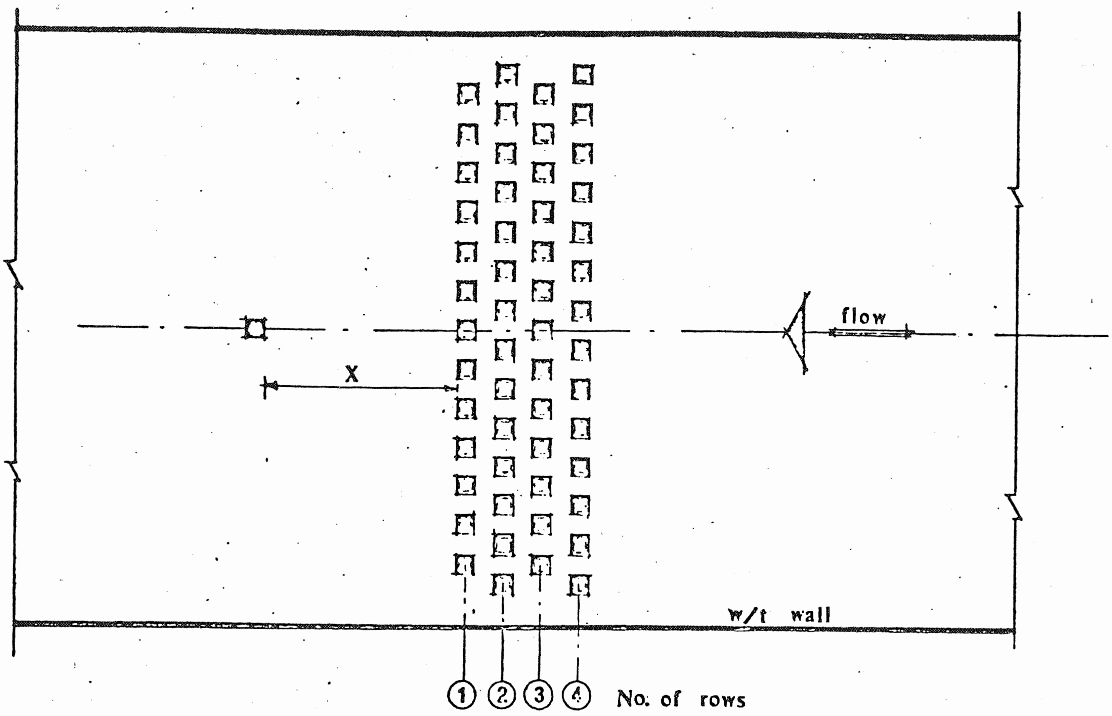


a)

Figure 7 Variation of the parameter $\frac{E + W}{H}$ with the frontal aspect ratio $\frac{L}{H}$ for different building forms for the results obtained from Evans' work, where E is the reattachment distance behind building, W is the building thickness, L is the frontal length of the building and H is the building height

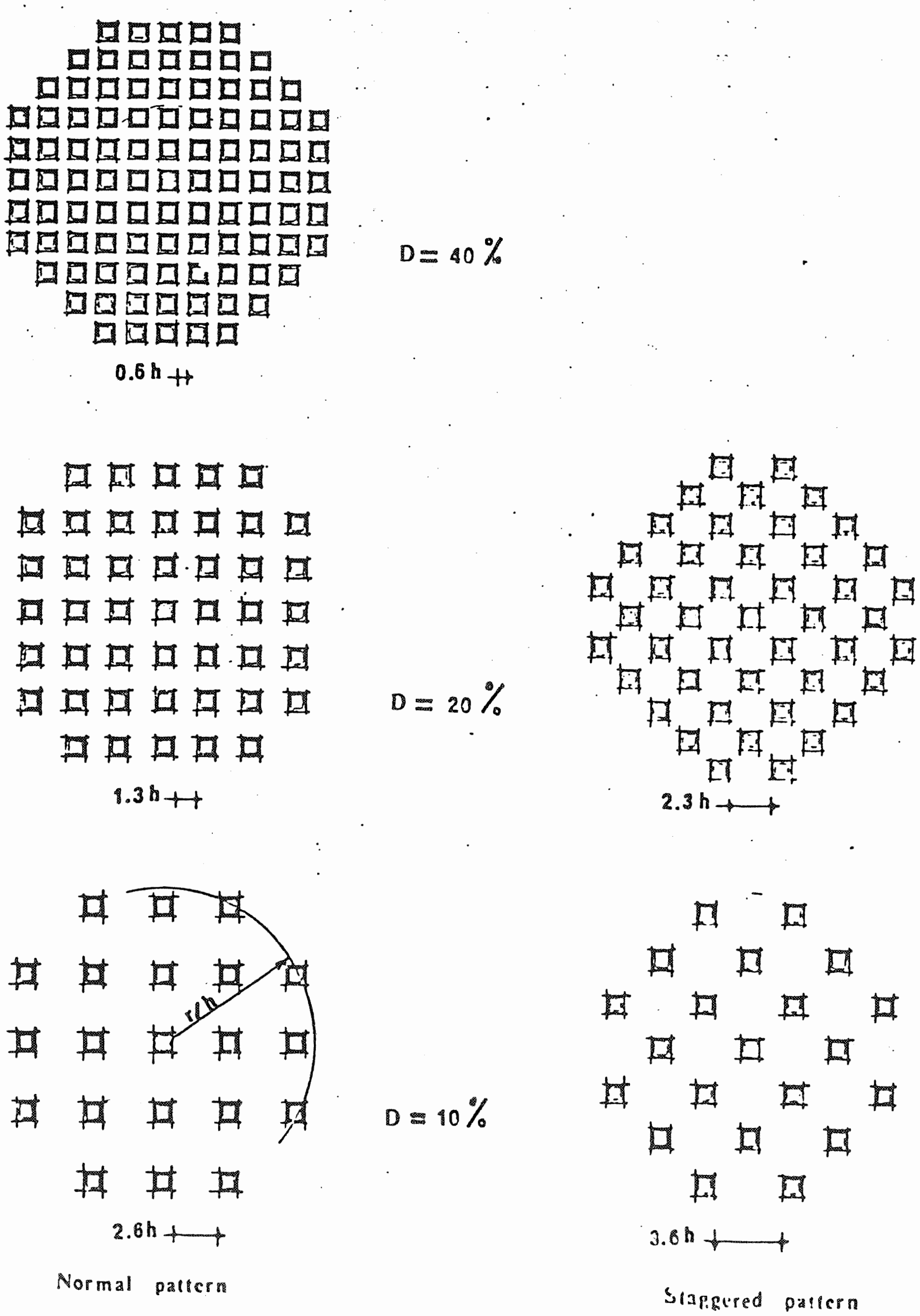
b)

a)



flow
X
w/t wall
1 2 3 4 No. of rows

)



D= 40 %
0.6 h
D = 20 %
1.3 h
2.3 h
r/h
D = 10 %
2.6h
3.6 h
Normal pattern
Staggered pattern

Figure 8 [illegible]

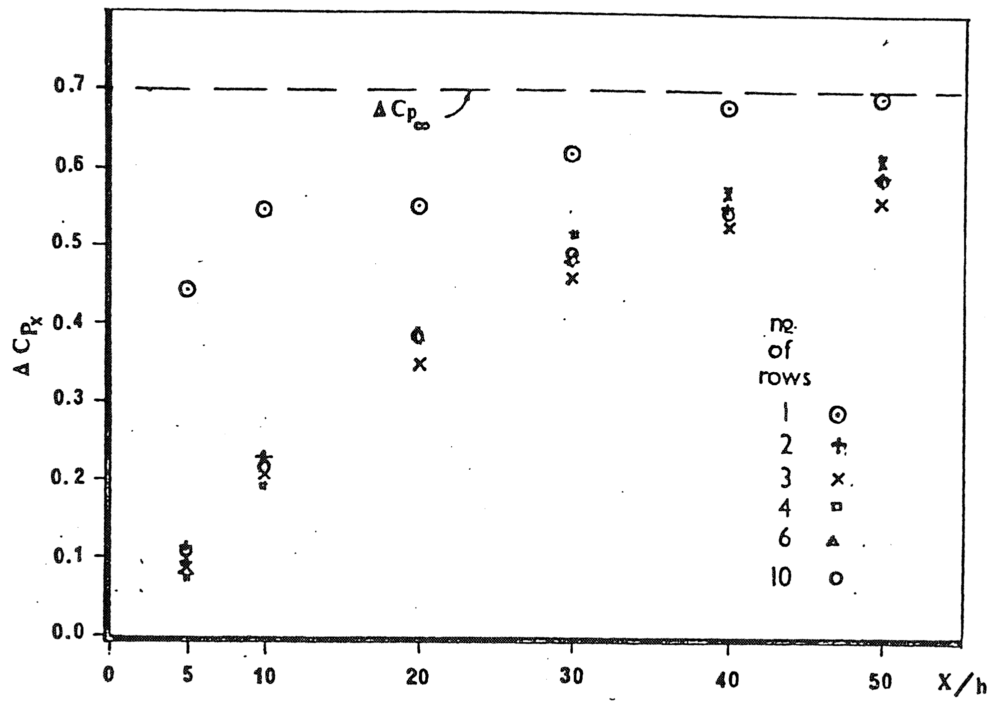


Figure 9 Pressure difference coefficient across the test building when it was isolated by a distançe x/h downstream of a group of various number of rows (group density 25%)

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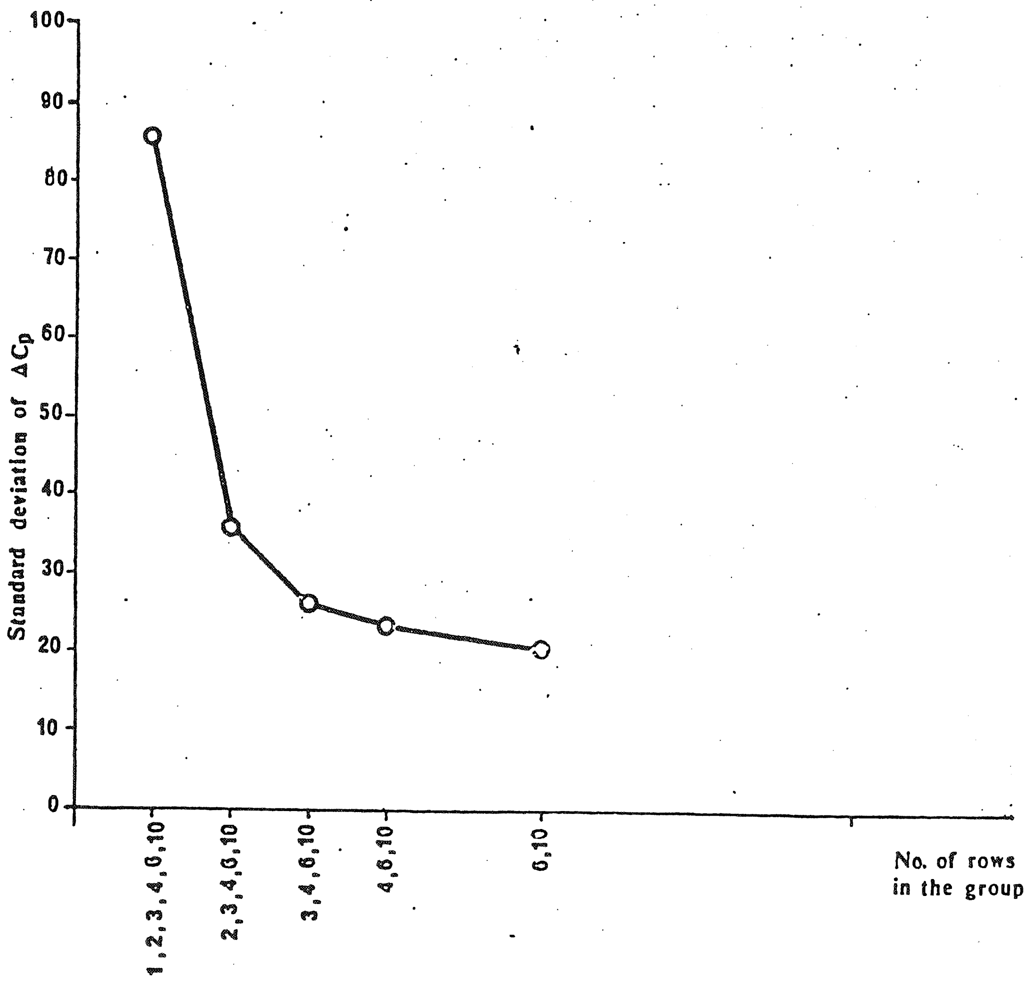

Figure 10 Variation of the standard deviation - of ΔCp across the test model - with different number of rows in the group

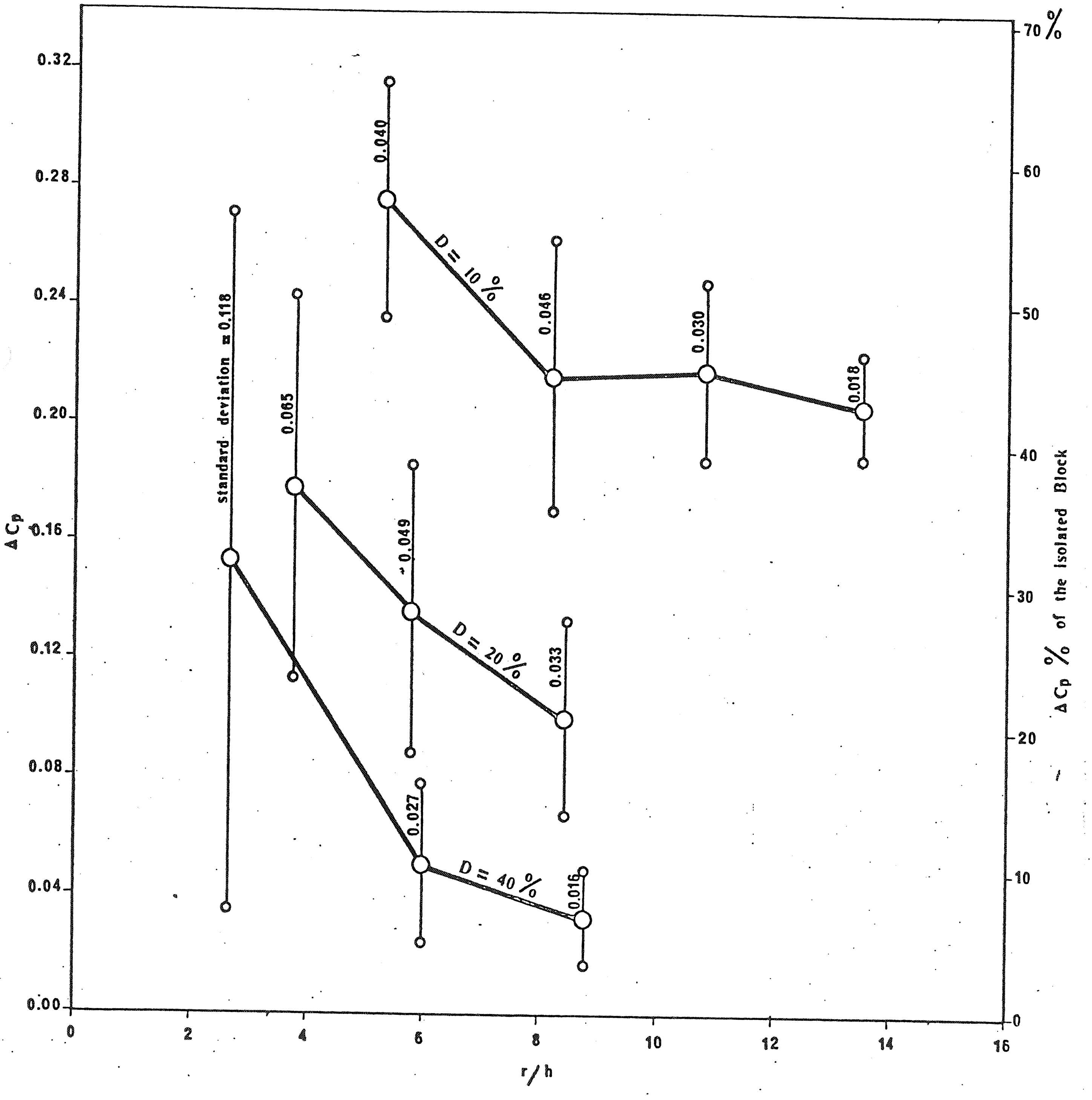

Figure 11 Variation of Δ Cp with radius of surrounding group, r/h, and density, D.

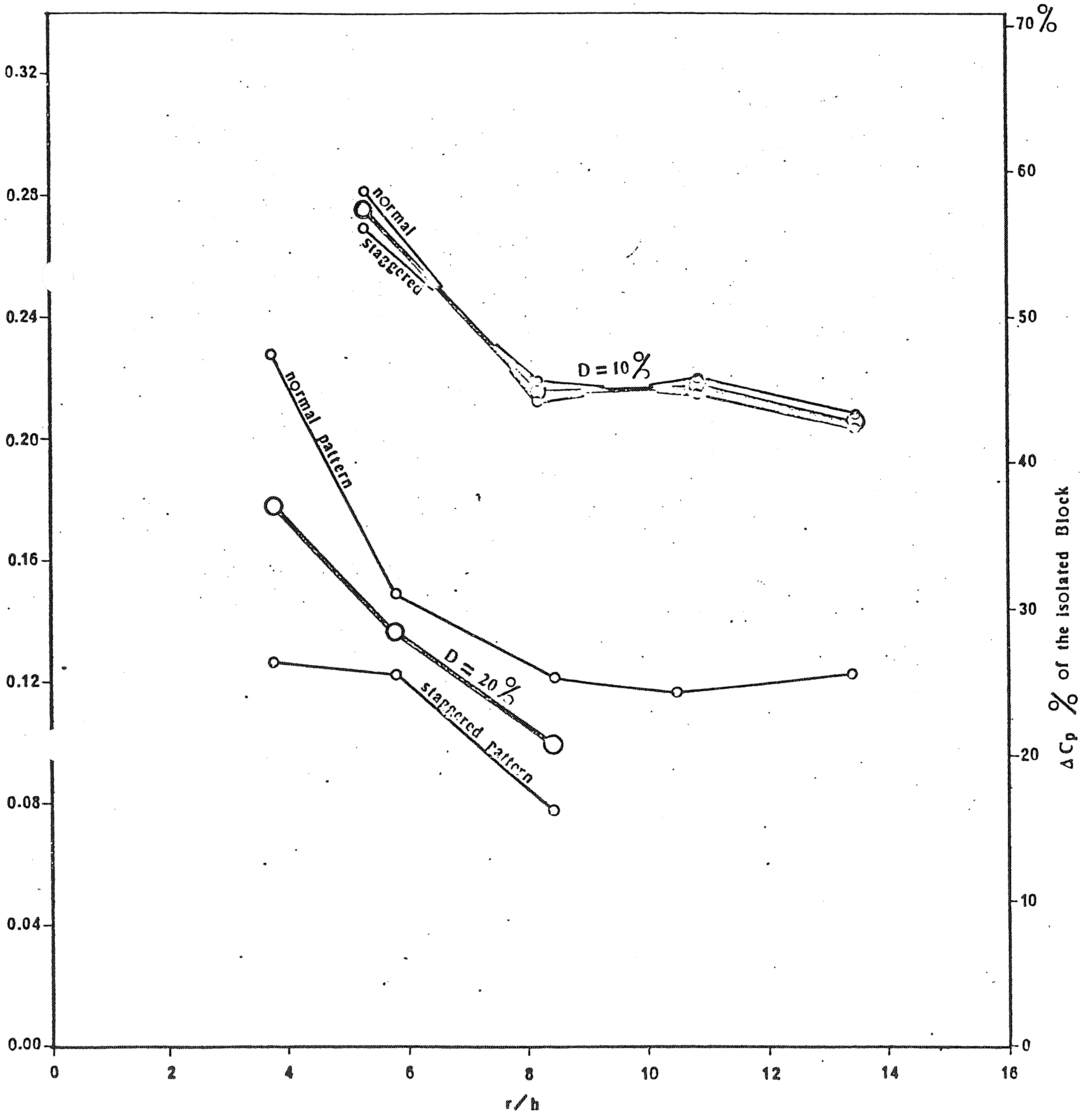

Figure 12 A comparison between the normal pattern and the staggered pattern for 10% and 20% densities

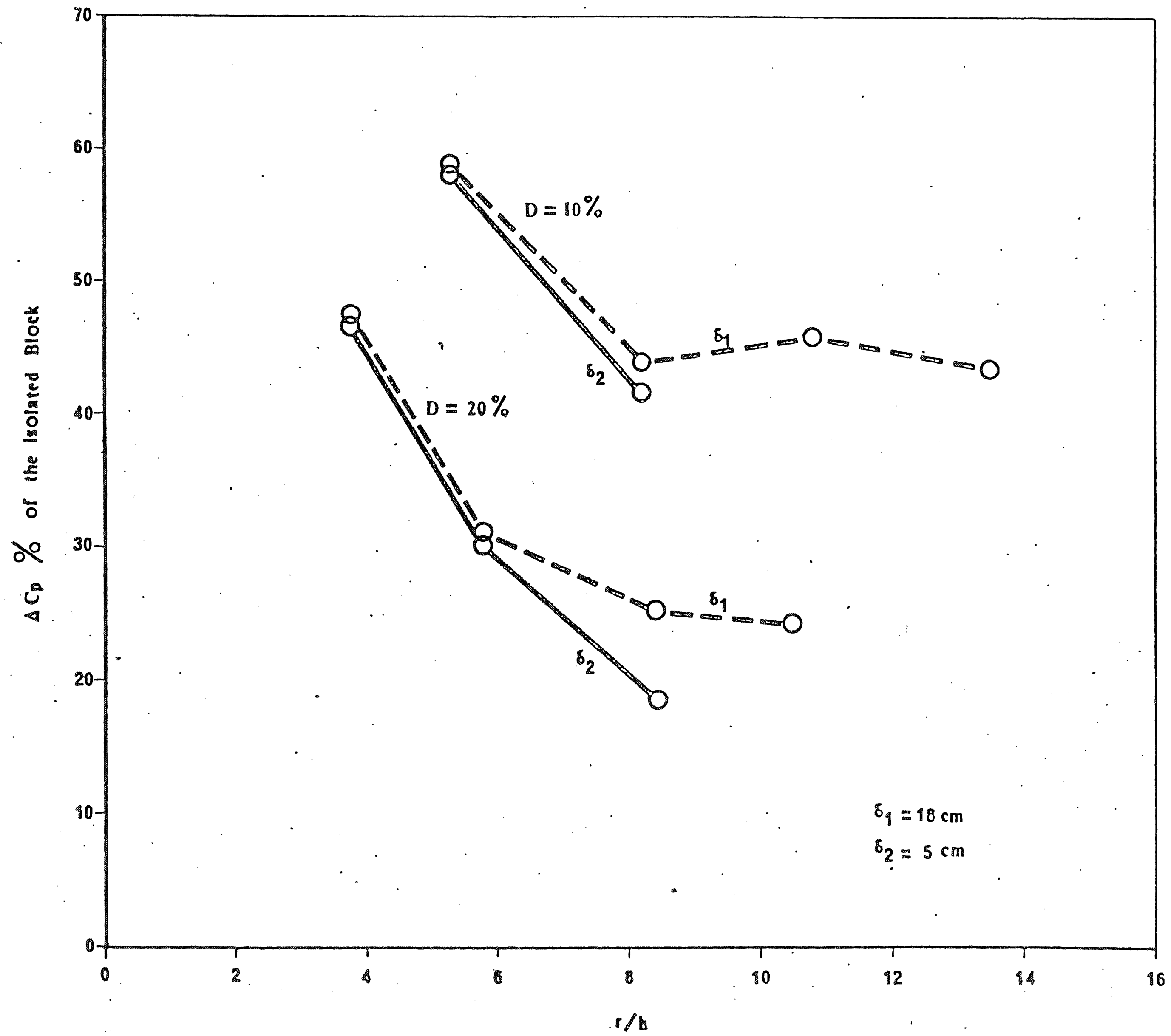

Figure 13 Effect of approaching boundary layer depth δ on ΔCp as a percentage of the isolated building ΔCp (normal pattern)

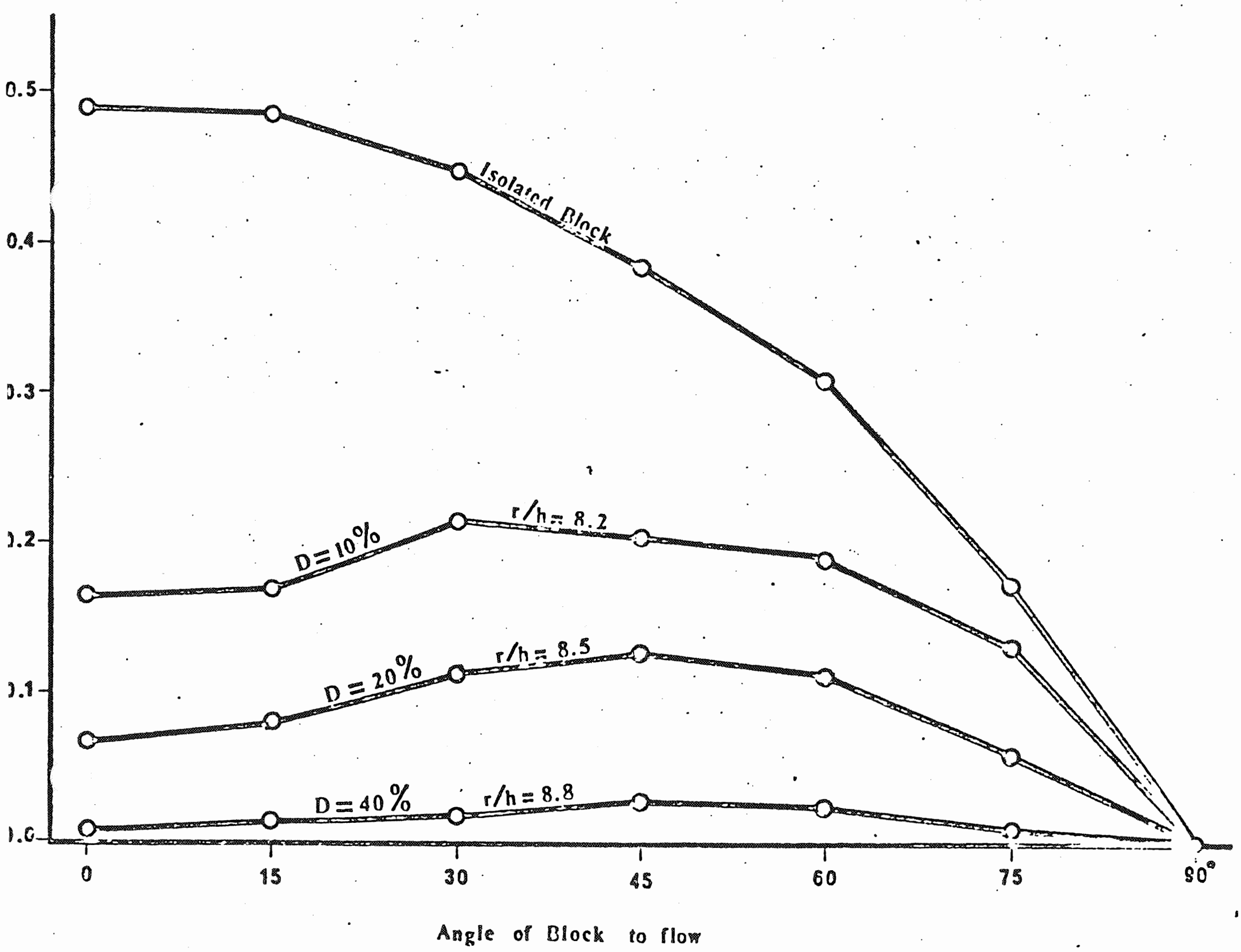

Figure 14 Effects of angle of incidence on Δ Cp for different densities compared with the isolated block.

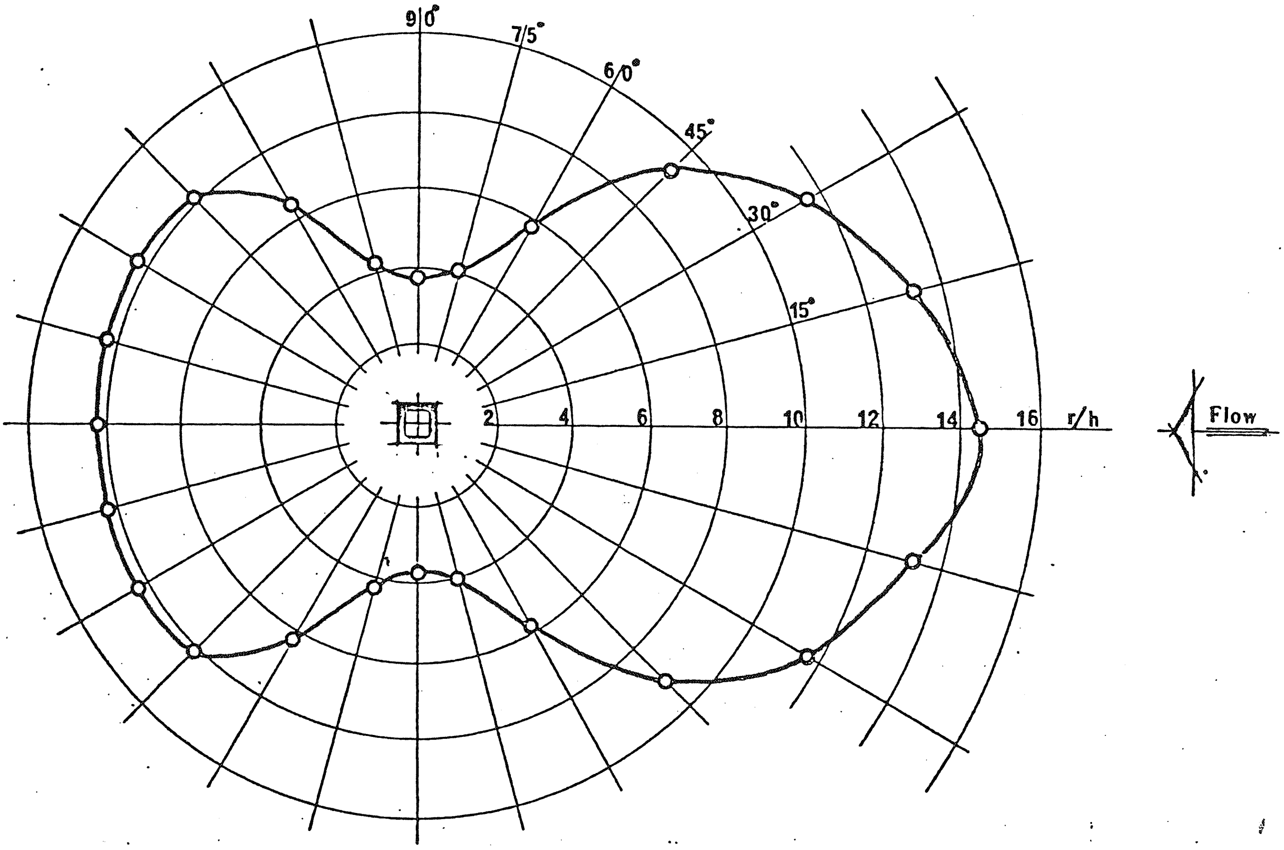

Figure 15 The area of influence around the test building when D = 10%, pattern = normal, δ = 18 cm., surroundings at 0°, ± 15°, ± 30°, ± 45° to the flow and the test building normal to flow direction