THE INFLUENCE OF BUILDINGS ON GROUND LEVEL WIND CONDITIONS*

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Changes in the morphology of modern cities with the increasing incidence of high rise construction, have significantly altered the built environment and its microclimate. In fact in many cases the presence of tall buildings has created what may be regarded as inhospitable micro-environments and even at times dangerous ground level wind conditions. As a result an acceptable wind environment in outdoor public areas, has become a major consideration for new building complexes, as too remedial steps which may also become necessary in existing problem areas.

The aim of this study was to examine those situations which led to severe amplification of ground level wind speeds in a built environment.

A case study conducted in Cape Town is used to illustrate how buildings may alter wind conditions and create severe wind problems for pedestrians. Guidelines and some practical steps are given for controlling the flow of air near the ground to within acceptable levels, in terms of pedestrian comfort and safety, are finally noted.

Veranderinge in die morfologie van moderne stede en die toenemende voorkoms van hoë multi-verdieping geboue, het tot gevolg dat die mikroklimaat binne die beboude omgewing aansienlik verander. Die teenwoordigheid van hoë geboue skep in baie gevalle onaangename mikro-omgewings en somtyds selfs gevaarlike windtoestande op grondvlak. 'n Aanvaarbare wind-omgewing in publieke buitelug-gebiede het dus 'n belangrike oorweging geword wanneer nuwe geboukomplekse opgerig word terwyl in sommige gevalle sekere remediële stappe geneem moet word om bestaande probleemgevalle te verbeter.

Die doel van hierdie studie was om die toestande wat tot verhoogde windsnelhede op grondvlak in 'n beboude omgewing aanleiding gee, te ondersoek.

'n Gevallestudie wat in Kaapstad uitgevoer is, is gebruik om die wyse waarop geboue windtoestande kan verander en ernstige probleme ten opsigte van wind vir voetgangers kan skep, te illustreer. Riglyne en sekere praktiese stappe wat geneem kan word om windvloei op grondvlak te beheer en binne aanvaarbare vlakke te hou met betrekking tot die gemak van die voetganger, word laastens gemeld.

**** Based on a study project, "The influence of buildings on wind flows and the design of the built environment" which was submitted in partial fulfilment of the requirements of the degree of Master of Town and Regional Planning at the University of Stellenbosch, in 1989.***

1 INTRODUCTION

In recent years problems associated with urban airflow have become more common as more tall buildings have been built and as cities and building owners have placed increasing emphasis on public plazas and open space. Since both the cost and economic benefits of such plazas and open space may be very high, significant financial losses may occur when such spaces are rendered unusable due to wind. The questions of safety and comfort of pedestrians, are also paramount.

The reason why developers are erecting higher and higher buildings is the increasing pressure on building land and the need to maximise floor space (Lee, 1987). However, buildings taller than 25-30 m may cause local winds at ground level that are much more intense than winds found elsewhere at ground level.

2 AIRFLOW AROUND A BUILDING

The pattern of airflow around a building depends on the characteristics of the incident wind, on the immediate surroundings and on the size and shape of the building itself. The wind cannot impinge directly on buildings which are no taller than their neighbours or are protected by nearby trees or other natural features of similar heights. In such a case the main stream of wind passes over the roof-tops, and the streets in the vicinity are usually sheltered unless the wind blows directly down their length (Isyomov and Davenport, 1975).

A building which is substantially taller than its surroundings (Figure 1) presents a large obstacle to the air flow, deflecting it both horizontally and vertically from its original course. One effect of this deflection is to cause increased wind speeds near ground level in the area around the building. As the wind approaches a tall building it gradually diverges until, at the windward wall, upward and downward flow are evident. Some of the air deflected downwards "rolls up" to form a vortex in front of the tall building. The vortex stretches out sideways and wraps around the building in a typical horseshoe shape. (According to Oke, 1978:266, if the building has sharp corners the flow accelerating over the top and around the sides becomes separated from the surface. Therefore the sides, roof and leeward wall experience "suction". Since air moves from high to low pressure, these areas are characterised by reverse flows i.e. in the opposite direction to the main stream.)

Maximum pressure occurs near the upper middle part of the windward wall (at about three-quarters of the height of the building) where the wind is actually brought to a standstill, and pressure decreases outwards from this stagnation point (Oke 1978:264) (Figure 1). The flow radiates from this central point, and a considerable mass of air flows downwards and outwards to be concentrated near ground level at the windward corners. In the process the air speed accelerates as the airstreams pass around the corners forming two jets of air which penetrate downwind for a distance equal to the height of the building. If the building is raised above ground on columns, or is pierced by an arcade or passageway, wind will flow at high speed through the openings at street level. This flow pattern gives rise to three main areas of increased wind speeds. The numbers (Figure 1) in these vortex-flow, cornerstreams and through-flow regions show the wind speeds likely to be encountered at pedestrian level as a ratio of those measured at equivalent points in the open. Clearly this building configuration can create conditions three times as windy as in the open, and therefore many times greater than in sheltered streets nearby (Lawson and Penwarden, 1977).

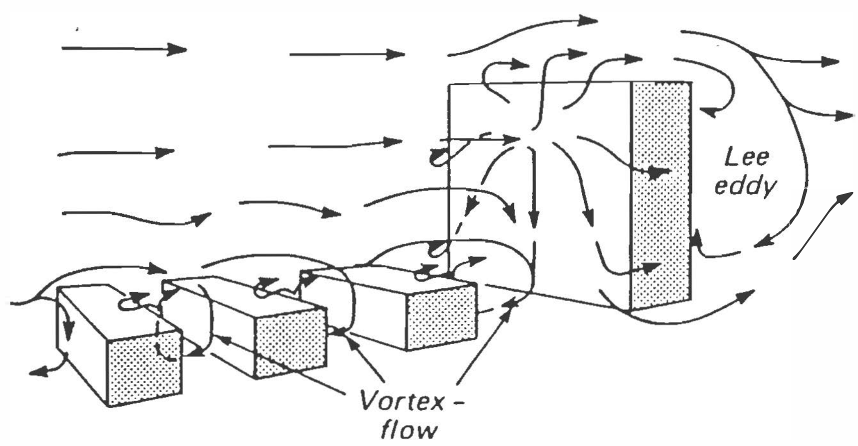

FIGURE 1.1. *Flow patterns over and between buildings of approximately the same height (left) and in the vicinity of a relatively much taller building (right). Source: Oke, 1978.*

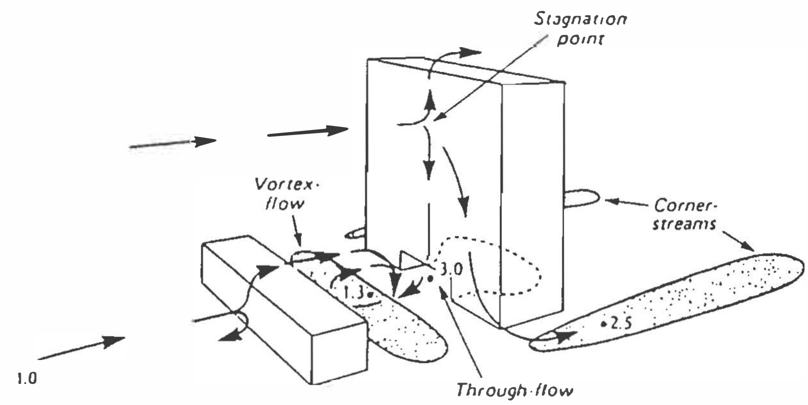

FIGURE 1.2. *Air flow around a tall building with lower buildings upwind. The three main regions of increased wind speed at pedestrian level (stippled) are illustrated, see the text for the meaning of the numbers. Source: Oke, 1978.*

3 WIND AND PEDESTRIANS

In the past, engineers and architects have been concerned mostly with wind forces on buildings and structures, and only recently has the pedestrian-level environment around buildings begun to receive attention. The importance of the pedestrian-level environment has been noted in that "successful" buildings also provide environments that enhance the activities of strolling, sitting and watching people going by in the course of everyday city life. High wind speeds around tall buildings can be very unpleasant and even dangerous, and some buildings have become notorious for the strong winds they are instrumental in generating.

Town planners and architects have become conscious of the need to avoid such high wind speed zones and they now require information at the planning stage about the probable wind conditions around proposed buildings. Such information is obtained from wind tunnel tests on models, and the frequency of occurrence of free wind speeds obtained from local meteorological data: on the basis of the latter data the frequency of high speeds around a building can be estimated.

Wind influences comfort both mechanically, through pressure exerted on surfaces and particle transport, and thermally, through the wind chill effect. With regard to the mechanical influences of wind, the most serious direct effect the wind can have upon man is to blow him over. This can cause injury and sometimes death: in England two old ladies actually died after being blown over by the wind close to tall buildings and in another incidence an old lady died of head injuries after being "lifted off her feet" by high winds near the base of a tall block of flats. There have also been numerous reports of people, and even vehicles, being blown over by strong winds near the corners of tall buildings on the foreshore in Cape Town. Although these may be regarded as extreme occurrences or even freak events, they could be avoided through careful design and layout of buildings: people' s lives and safety should not be placed at risk as a consequence of poor planning and design.

4 A CASE STUDY OF THE PEDESTRIAN LEVEL WIND ENVIRONMENT AROUND THE CIVIC CENTRE IN CAPE TOWN

4.1 Introduction

In recent years quite a few cases have been reported in the press of injuries received when people were blown over by severe winds in the vicinity of the Civic Centre in Cape Town. The aim of this study was to determine the pedestrian level wind environment around the Civic Centre during a south-south-easterly wind episode.

4.2 Description of the site

The Civic Centre is situated in the city centre of Cape Town. It is 104 m high, 184 m wide and 20 m deep on a SW-NE axis, with an extension to the north-west which is approximately 35 m high, 100 m wide and 90 m deep.

As shown in Figure 2, a four lane dual carriage-way passes under the two outer supporting arches which support the building at ground level.

The Civic Centre is surrounded by buildings of various heights of which the Cape Town Centre to the north-west is the most significant (this tall building can be seen on the right of Figure 2). The Cape Town Centre is approximately 80 m high and plays an important role in the aggravated wind conditions experienced near the Civic Centre, and is therefore important in the context of the investigation.

4.3 Experimental procedure

Due to the excessive costs involved in wind tunnel testing, the following in situ experimental procedure was chosen for the study.

An anemo wind speed indicator with a built-in compass was used to measure maximum gust wind speeds at various recording stations around the Civic Centre. (It is the unexpected nature of the peak gusts that cause people to be blown over.) The recording stations were mostly confined to areas used by pedestrians on a daily basis, thus, as can be seen in Figure 3, most of the stations are on sidewalks around the buildings. The peak gust velocity over a period of ten minutes was recorded at every station.

Measurements were taken during three separate southerly wind episodes (the prevalent wind in this area) in Cape Town. In order to determine the precise direction and free wind speed in the vicinity of the Civic Centre on these three occasions, the data obtained from the Weather Station at D F Malan Airport were compared to those obtained from the docks at Cape Town Harbour.

Due to the fact that the patterns of wind data obtained on the three different occasions, were very similar, the day when the highest wind readings were recorded (i.e. October 2, 1989) was chosen for the study. These wind data vividly illustrate the severe wind problems encountered around the Civic Centre. Readings were taken between 14:00 and 18:00 when the wind velocities peaked.

FIGURE 2. *View of the Civic Centre from the north-west, showing how the complex straddles the dual carriage-way.*

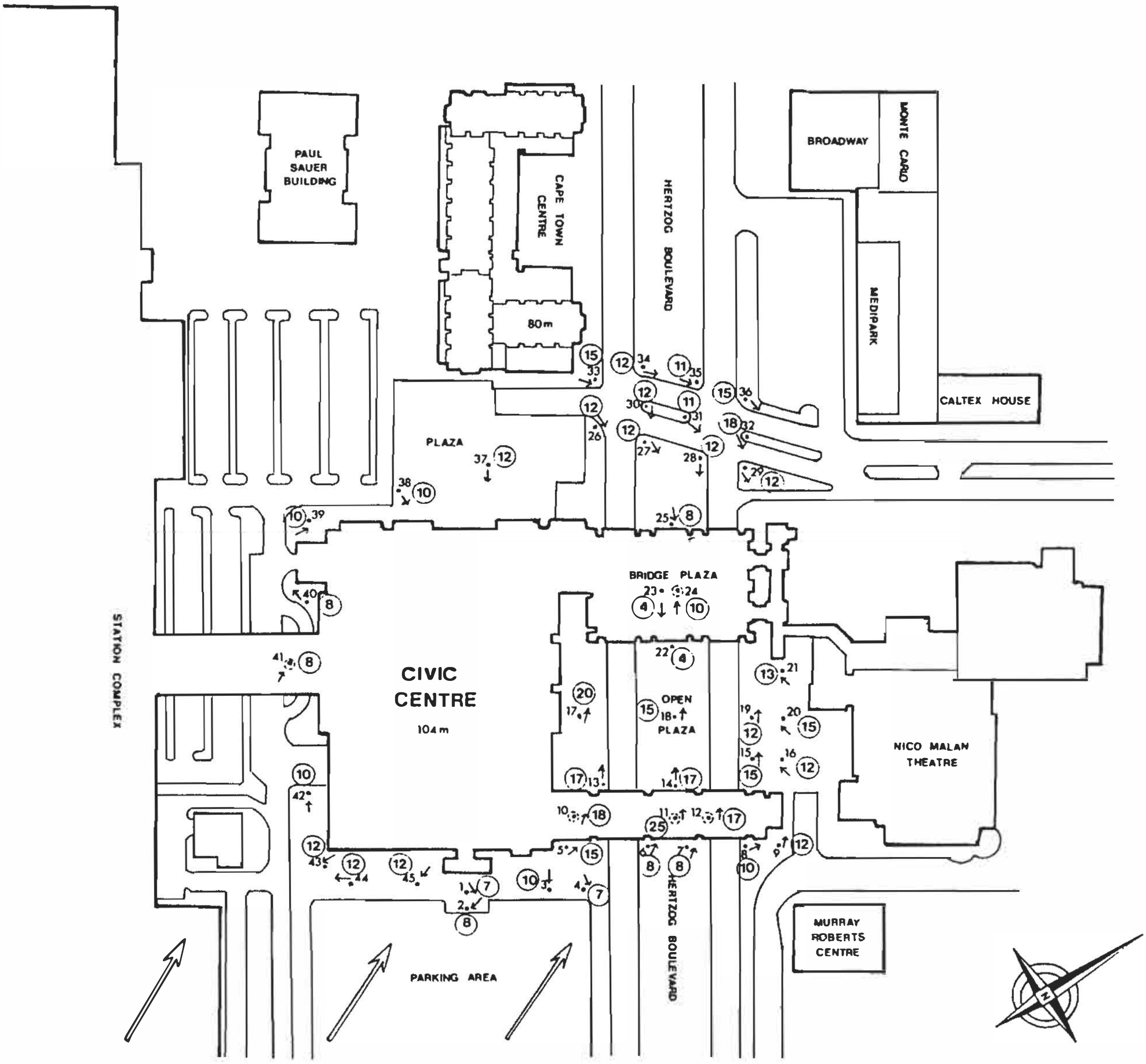

FIGURE 3. *Plan of the Civic Centre and surroundings. The large arrows indicate estimated free wind direction, while the small arrows indicate the wind direction measurements recorded at positions 1-45. Wind speed readings in metres per second recorded at each position are circled.*

4.4 General wind data obtained

Table 1 gives prevailing regional wind characteristics for the study period.

The wind speeds measured at the docks (a mean speed of 9 m/s was recorded), were higher than those measured at D F Malan Airport and the wind directions also differed slightly. It was found that the wind direction was more south-south-easterly at the docks. The reason for this phenomenon can probably be ascribed to orientation of Table Mountain relative to the prevailing wind. Table Mountain forms an obstruction directly to the south of the study area and probably causes southerly winds to be deflected to a more south-easterly direction (Figure 4). The higher wind speeds measured at the docks are possibly due to an "accelerative effect" the mount has on southerly winds.

Measurements recorded at an open site 500 m south-east of the Civic Centre correlated with those obtained from the docks. For the purpose of this study it was therefore assumed that a 9 m/s SSE "free" wind prevailed at the study area.

4.5 Findings of the study

Maximum gust wind speeds measured at the recording stations around the building, are shown in Figure 3. The wind directions recorded at these points are indicated by means of small black arrows whereas the free wind direction (south-south-east) is represented by the long open arrows.

TABLE 1 WIND DATA RECORDED AT THE WEATHER STATION AT D F MALAN AIRPORT ON 89-10-02.

Wind direction	South
Maximum hourly wind	11,0 m/s
Maximum gust	19,0 m/s
Mean wind speed	7,8 m/s

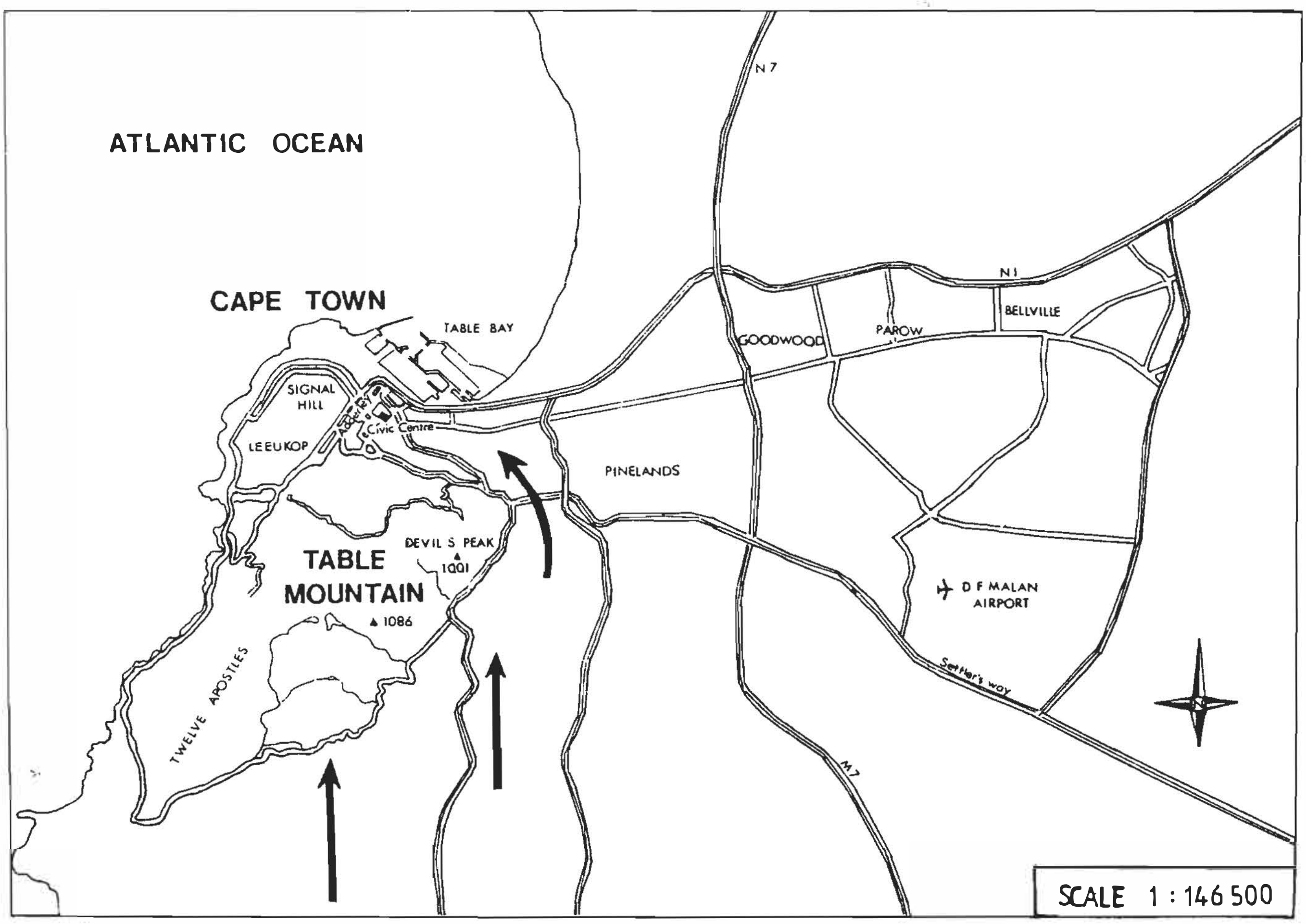

FIGURE 4. *The influence of Table Mountain on southerly wind patterns.*

4.6 Discussion of results

The results show that the 104 m high Civic Centre has a considerable influence on the wind environment around it.

The first readings were taken on the sidewalk in front of the main south-east face of the building (positions 1-9 and 43-45) (Figure 3). This area is regularly used by pedestrians. According to the arrows at sites 43, 44, 45 and 1 to 7 the wind direction at pavement level is directly opposite to that of the free wind. This is probably due to the fact that the building is orientated with the main face almost normal to the prevailing wind (south-east to south-south-east), and hence flow is deflected down the face of the building causing a windward eddy to develop. A highly turbulent vortex flow thus develops at ground level, (i.e. between the parking area and the Civic Centre) with gusty, swirling winds which often whip up dust and litter.

The four passageways underneath the building give direct communication between the windward and leeward sides of the building. The wind is "sucked" through these openings as "through-flow" into the zone of low pressure which develops on the leeward side of the building. A jet of air is therefore formed through the passageways. The wind speeds that were measured in this region (positions 5-21), were of the highest recorded at any point around the building. With the wind gusting regularly up to 18 to 20 and even 25 m/s, in the arcade and on the plaza, people had great difficulty in retaining their balance particularly when a gust caught them sideways on. Some wind was deflected off the Nico Malan Theatre building to form easterly winds at ground level, Stations 16, 20 and 21.

The situation near the bridge plaza was found to be quite different. At station 22, just to the south-east of the bridge plaza, variable wind conditions were experienced. No specific wind direction could be determined and the wind speed varied between 3 and 5 m/s. In order to explain this phenomenon, the wind conditions experienced under and just to the north-west of the bridge plaza must be considered. The wind direction recorded at station 23, under the bridge plaza, was north-westerly with a speed of 4 m/s whereas at station 25, it blew with a speed of 8 m/s from an almost direct westerly direction. A likely reason for this is that some of the air that is deflected over the top of the building, as well as from the accelerated airstream that passes around the south-western corner of the building (stations 25-42) is sucked through the opening to the low pressure zone underneath the bridge plaza. This north-westerly wind is not strong enough to penetrate the open plaza but acts as a buffer, forcing the south-easterly wind recorded in the open plaza to escape over the top of the bridge plaza. To substantiate this theory a south-easterly wind with a velocity of 10 m/s was measured at station 24 on the bridge. The collision between the north-westerly and south-easterly winds at station 22 would appear to cause the variable wind conditions experienced here.

The north-westerly wind direction recorded at certain stations (25, 28, 30 and 35) is probably a result of the air that is deflected over the top of the building. Since the leeward side of the building where a low pressure zone exists, experiences "suction", these areas are characterised by reverse wind flows.

Stations 26-39 are all influenced by the corner-stream effect the building has on the specific wind. This accelerated airflow passes around the south-western corner of the building to form a jet of air which continues downwind past the Civic Centre for a considerable distance. It seems likely that the Cape Town Centre just to the north-west of the Civic Centre, helps to channel and accelerate the corner-stream airflow in a north-easterly direction.

At the street corner at the base of the Cape Town Centre (in the vicinity of station 33 in Figure 3) serious accidents have occurred in the past. People have been blown over or have fallen in front of moving traffic as a result of strong gusty wind conditions. One or two cases have also been reported of delivery vans being blown over. The most recent incident occurred on 1990-02-09 when a double-decker bus was overturned by a hurricane-force wind. Fortunately nobody was injured as all the passengers had alighted seconds before the bus crashed on its side.

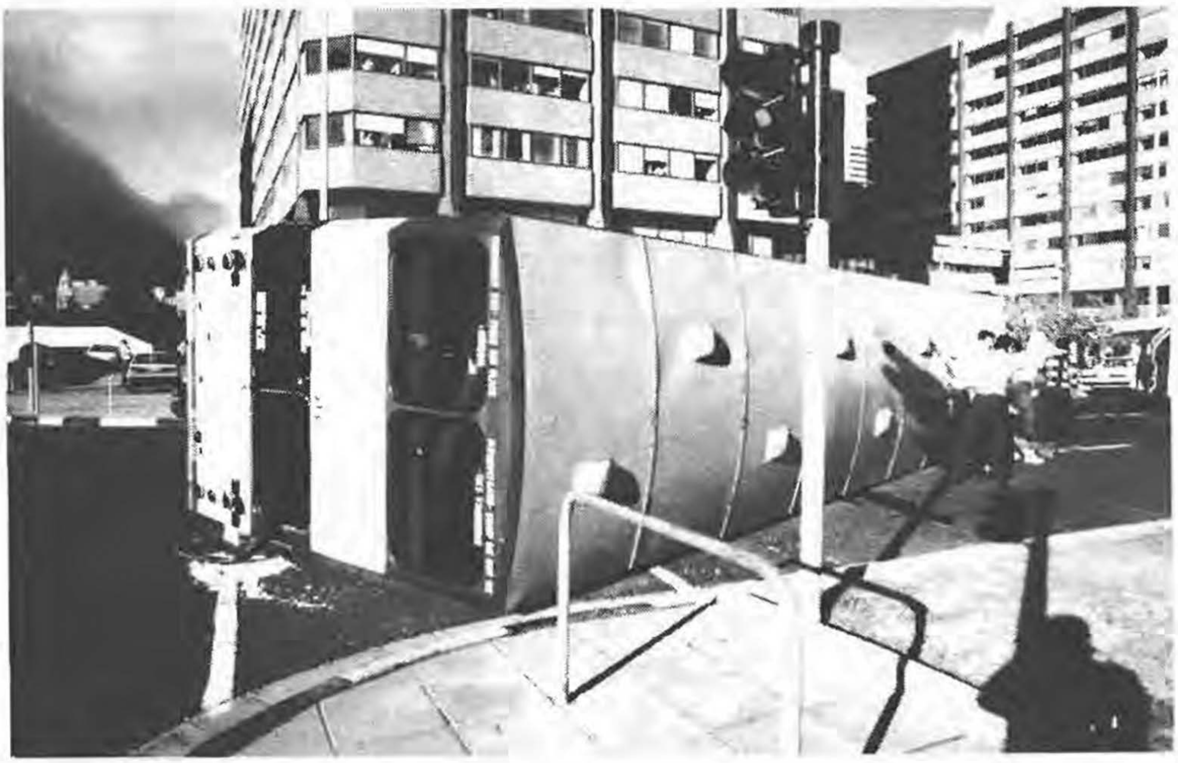

FIGURE 5. *Bus blown over by wind.*

The venturi-effect which causes hazardous wind conditions is much more intense when southerly to south-south-westerly winds prevail: under these conditions the more direct line the wind takes across the plaza between the two buildings, cause much higher wind speeds. Safety hand railings have been erected to assist pedestrians in this area (Figure 6).

4.7 Criteria for assessing acceptable wind speeds

The wind speed data recorded at the Civic Centre were evaluated in terms of the four criteria (comfort, discomfort, unsafe for walking and physical danger) of Hunt et al (1976) and Murakanie et al (1979) (Table 2).

TABLE 2 AN EVALUATION OF THE RECORDED MAXIMUM GUST WIND SPEEDS AT POSITIONS 1-45 IN FIGURE 3 IN TERMS OF THE CRITERIA OF HUNT ET AL (1976) AND MURAKAMI ET AL (1979).

Criteria	Description	Gusty winds	Stations in Figure 3
Comfort	No noticeable effect on performance.	0 - 5 m/s	22, 23
Discomfort	Most performance uneffected but footsteps sometimes irregular. Raises dust and loose paper.	6 - 8 m/s	1, 2, 4, 6, 7, 24, 39, 40
	Walking irregular and difficult to control. Hair blown straight.	9 - 14 m/s	3, 8, 9, 16, 19, 21, 25, 26, 27, 28, 29, 30, 33, 34, 36, 37, 38, 41, 42, 43, 44, 45
Unsafe for Walking	Walking impossible to control and dangerous for elderly persons Body blown sideways or leeward.		5, 10, 12, 13, 14, 15, 17, 18, 20, 31, 32, 35
Physical danger	People blown over	> 20 m/s	11

The results are largely self-explanatory and clearly show that at many points around the building, conditions were unsafe for pedestrians on the day the measurements were taken. Conditions were especially uncomfortable and dangerous in the passageways underneath the building and on the open plaza.

Because of the problems which have since the completion of the Civic Centre become evident and on the findings of this case study, it would appear that less than adequate attention was given to the influence this and adjacent structures would have on the wind conditions at ground level and that the particular configuration of these structures would cause under certain wind conditions an unacceptable pedestrian environment.

As can be seen in Figure 6, handrails have been provided at several pedestrian-crossings to assist people to negotiate these spaces during strong windy conditions. These steps represent the minimum that can be taken to assist pedestrians - the only remedial action which has been taken around the Civic Centre to alleviate these unsatisfactory conditions.

FIGURE 6. *Street corner at the base of the Cape Town Centre, facing the entrance to the Civic Centre.*

5 GUIDELINES FOR REDUCING HIGH INDUCED WIND SPEEDS AT PEDESTRIAN LEVEL

At the planning stage it is necessary to define what kind of activities might be carried out in particular areas around a building. For example areas which are to be used for leisure will have lower acceptable wind speeds than car parks. By careful consideration of regional wind direction frequencies and wind speeds from meteorological data, it is usually possible to predict the likelihood of comfort thresholds being exceeded. On the basis of this it may prove necessary to exclude pedestrians from particular zones: although this is not always possible as one still needs to gain access to buildings and existing shops. (Melbourne & Joubert, 1971).

As a guide to assist planning and design decision-taking, the following are noted.

1. Buildings will only induce high ground level wind speeds if a significant part of the building is exposed to direct wind flows. One may assume as a general rule that a building should be regarded as potentially exposed for any particular wind direction if half of the building height is clearly above those buildings which are upwind of it and which could provide shielding.
2. An upwind building of half the height is reckoned to shed a wake region of low wind speeds which will cover about three-quarters of the downwind building under construction, and the direct wind flow striking the building above this wake will tend to be deflected up and around rather than downwards. The shielding effect of upwind buildings is one of the most significant factors to be taken into account when an assessment of environmental wind conditions is being made, and the shielding provided by single buildings can be effective for between 500 m and 1 000 m downwind (Isyomov and Davenport, 1975).
3. If a building is regarded as being exposed for some or all wind directions, the following building configuration factors should be taken into account;
   (a) Rectangular buildings with a main face rising clearly from ground level, normal to any of the unshielded prevailing wind directions should be avoided as these are the most common cause of environmental wind problems (Kamei & Murata, 1979).
   (b) Rectangular, tall buildings can be put on a wide podium so that high winds are confined to the roof of the podium and therefore kept above street level (Figure 7(a)). A smaller podium or a wide canopy can be used if a one storey high vent space is provided, but this is a less likely solution because it eliminates an entire storey of the building (Figure 7(b) and (c)). Canopies, however (unless very extensive), do little to ameliorate high wind speeds induced at the corners of buildings (Hanlon, 1972).
   (c) Buildings with circular or near circular planform, promote lateral flow and induce little downward vertical flow, and hence they are to be preferred in exposed situations. Circular buildings do induce high wind speeds at the maximum width normal to the wind direction, similar to that induced at the corners of rectangular buildings. However, in the case of circular buildings, this is caused by acceleration of the local flow around the cylinder. This latter wind characteristic can be reduced to a large extent by placing relatively low upwind shielding; this is not so for rectangular buildings, because much of the flow around the corners originates from flow induced by wind flowing downwards over the windward face from higher levels (Merati et al, 1982).
4. Arcades at the base of buildings can induce high wind speeds due to a combination of direct wind and wind flows down the face of a building being funnelled through the openings. In such cases it is usually necessary to provide some means of sealing them with revolving doors or mechanically operated sliding doors on strong windy days (Gerhardt & Kramer, 1986).
5. Roofs can be built over pedestrian areas to reduce wind speeds. The extra cost may run into hundreds of thousands of rands, but may be the only means to create an acceptable environment.
6. The installation of floor-to-ceiling screens, positioned so as to form a simple labyrinth, can reduce the flow of wind beneath a building, while still maintaining adequate pedestrian access. Alternatively, solid screens with doors can be used.
7. The provision of handrails at strategic points near the base of tall buildings may give pedestrians some support or assistance during extreme wind conditions. This is the minimum that should be done to assist people in an otherwise unacceptable environment.
8. The use of vegetation may also be useful in absorbing horizontal wind energy in pedestrian areas. However, trees and shrubs do not provide effective protection from downdraft winds (Arens, 1981).

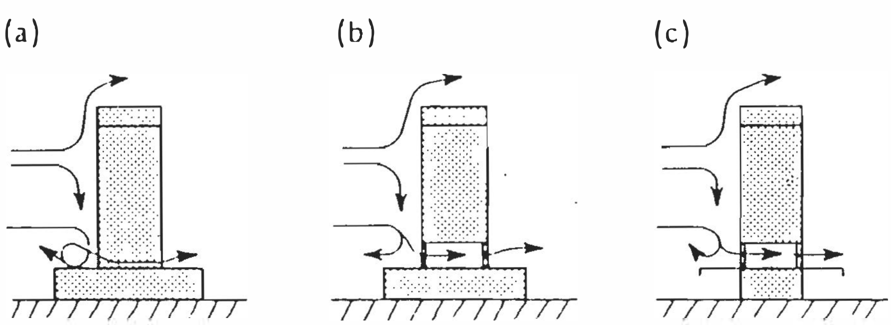

FIGURE 7. *Tall building designs helpful in alleviating undesirably increased wind speeds at pedestrian level (modified after Hanlon, 1972).*

6 CONCLUSION

In practice many factors, physical, social and economic, interact to determine the nature of the parameters which should be considered with respect to the design of the built environment. Experience has shown that the effects of wind are often considered too late in the planning process with unfortunate and generally expensive results. At all times, the town planner needs to be able to assure himself that all potential problem areas have been studied, and must be satisfied that people's safety will not be put at risk through failure to take cognizance of the potential influence buildings may have on wind conditions at pedestrian level.

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