PROBLEMS OF VENTILATION IN HIGH DENSITY LOW RISE HOUSING IN BANGLADESH (HOT-HUMID)

BY

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DEDICATED TO QUDSIYA, MASHUQ AND MARUF WITH LOVE AND AFFECTION

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CONTENTS

TITLE PAGE

INTRODUCTION

As a yong country Bangladesh is faced with enormous problems. Housing is is one of them, a very significant one. With meager means all the problems of housing can not be solved in a short span of time. But right policy or decisions may be made at a very early stage.

Climate play a significant role in determining the nature of planning, layout and individual house type in a scheme. In a hot humid climate like Bangladesh, ventilation is probably the most important single climatic factor in influencing the house design. Because most of the year, from mid February to mid November, is warm and the humidity is high. Since cooling and dehumidification or air conditioning is beyond the means of the people, proper ventilation is the only way to improve the comfort conditions. Evaporative cooling can help to ease the condition of discomfort due to sticky heat. To create a comfortable indoor condition is probably the objective of building a shelter.

In general indoor conditions similar to shaded outdoor condition is the optimum that can be aimed at. This is relatively easy when wind is blowing with a reasonable velocity. Unfortunately it is not so at all times. At times the outdoors are very calm. So it would be very helpful if air movement could induced in addition to provision for adequate oppenings. In that case one might have the comforting feeling of continuous breeze indoors.

Bangladesh is a land hungry country. So the term high density is very popular with the decision makers. Enough lip service is done to the question of density. High density is always associated with the vision of high rise apartments representing a western model which has already been discarded by western communities. But the myth still looms over Bangladesh. In the case study done, the housing scheme consists of three storey buildings with a gross density of only 80 persons per acre. It can be easily shown that a higher density can be achieved with adequate open spaces, assuming a single storey solution. Stevens' chart (33) given in the appendix can be used as a guide.

In the present dissertation while discussing the problems of ventilation it has been assumed that the house types are one or two storied and the density is between 100 and 150 persons per acre. Hence the term 'high density low rise' have been used in the title.

In recent times much scientific studies have been done to objectively determine and predict the air flow, in both cases of natural and induced ventilation. Previously it was only subjective suggestions. Keeping that in view the objective of the dissertation is to analyse the climatic data of Bangladesh; to find out how the climatic condition affect the comfort condition of the people, to understand and be aware of all the factors that govern the air flow and finally to be able to devise ways and means to maximise the effects of ventilation to achieve the desired indoor conditions of comfort.

CHAPTER ONE CHAPTER ONE

[illegible]

1.1.0. POLITICAL

Bangladesh was under Hindu, Buddhist, Muslim and British rules. The country finally had self rule in 1971. Muslim rulers of Dehli extended their domain up to Bengal in the fifteenth, sixteenth and seventeenth century. The British first got territorial control of Bengal in mid eighteenth century. Through out history mutual antipathy, antagonism, often associated with violence, have coloured the relations between Hindu and Muslims of Bengal. In 1906 the political party of Muslim League was formed in Dacca which in 1940 demanded Pakistan, a separate land for Muslims.

1.1.1. In 1947 when indipendence of the Indo-Pak subcontinent was agreed, the partition act of Bengal was materialised. At that time the present map of Bangladesh emerged and was known as East Pakistan, a province of Pakistan.

1.1.2. Finally in December, 1971 through a bloody war the province of East Pakistan became free of the dominant part, West Pakistan. This became the independent souverign state of Bangladesh. This is a democratic country with central planning.

1.1.3. At present administratively the country is devided into nineteen districts. The districts are devided into subdivisions and each subdivision has several 'thanas'. Thana means the area under the jurisdiction of a police station. There are altogether 54 subdivisions, about 400 thanas and 50 thousand villages.

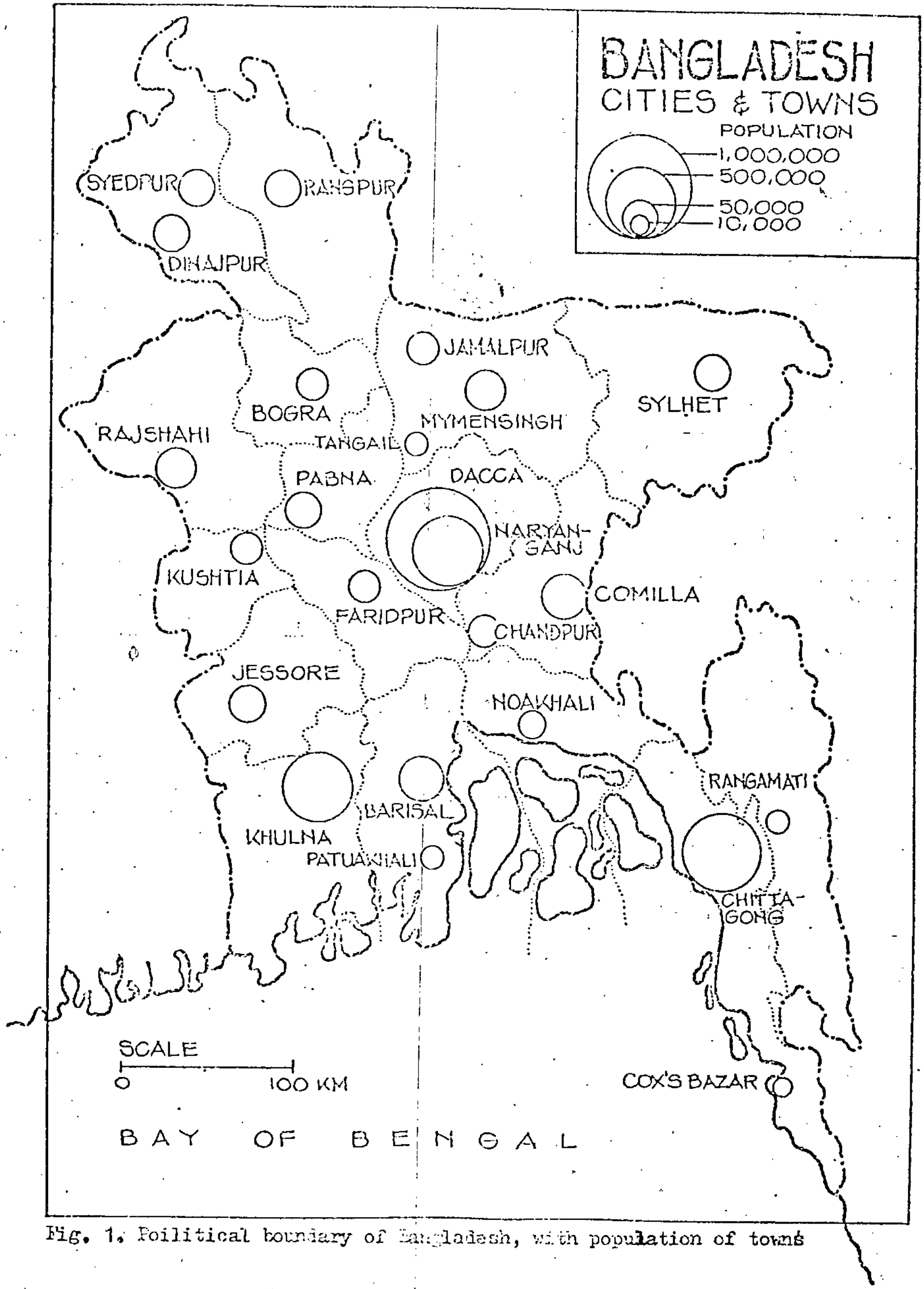

Fig. 1. Poilitical boundary of Bangladesh, with population of towns

1.2.0. GEOGRAPHY

Bangladesh lies between 20° - 30' and 26° - 45' North latitudes and 88° - 10' and 92° - 56' East longitudes. Her area is 55,126 sq. miles. According to physical features Bangladesh may be devided in to the following two parts:

A. The vast alluvial plain.

B. The fringe hill country of East and South East.

1.2.1. The flat plain is formed by the alluvial deposit of the three mighty rivers and its tributaries. The Padma, the Meghna and the Jamuna with all their tributaries form one of the most remarkable network of rivers in the world. The activity and behaviour of the rivers are of utmost importance in determining the economic condition of the people. The rivers serve as drainage channels, ensure an abundent supply of fish, provide cheap and convinient means of transportation and above all act as a great natural fertilizing agency. Even the building material sand comes from the river beds.

1.2.2. The hill country occupies less than 10 percent of the total land. Chittagong and Sylhet districts constitute the hilly areas. The ridges here are generally 60 to 90 metres above the sea level where as the plains are only 3 to 5 metres above the sea level. The hills are fringed by low bench lands about 30 metres above the sea levels. Some of these areas are gainfully utilised for the cultivation of tea.

1.2.3. Structural bearing capacity is specified to be one ton per sq. ft. in all parts of the country except in coastal districts where clay is the major sub soil formation. But actual bearing capacity in most parts of the country is much higher than the specified quantity of one ton per sq. ft.

1.2.4. Economically Bangladesh is a very poor country. 25 years ago it had surplus food production. To day there is a recurrent shortage of 10 to 15 percent of total need every year. Main agricultural products are jute, rice, tea, sugar cane and various fruits abd vegitables. Major exports are jute, tea, leather, etc. Major imports are food, fuel, textile products, machinaries, etc. Jute industry is by far the largest industry. Major part of foreign investment is British.

1.3.0. POPULATION

Population is a function of birth rate as well as death rate. The death rate in recent times has fallen considerably from 30 persons per thousand in 1947 to 17 persons per thousand to-day. But the decline in birth rate is much slower. Birth per woman is 6•5 to-day compared to 7 at the time of partition. Hence the present annual rate of population increase is 3•4 percent and will continue to be so for some time to come. Last years' estimates have revealed a rapid rate of increase of population in Bangladesh area inspite of many serious natural calamities and epidemics, limited social change and meager economic development. (5)

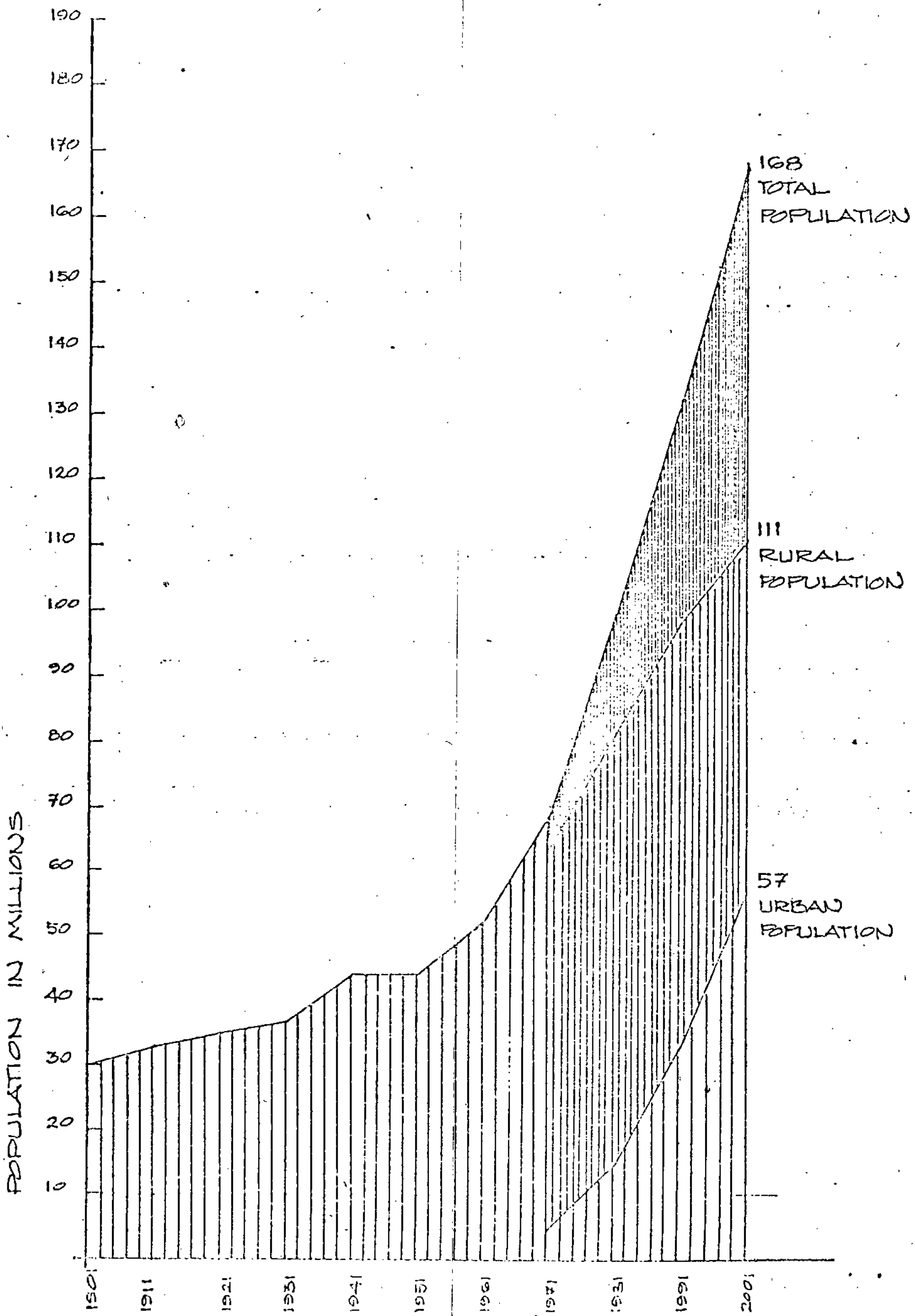

FIG. 2. BANGLADESH POPULATION CURVE FOR THE 20TH CENTURY WITH ESTIMATED PROJECTIONS.

This is expected to decrease to 2·9 percent by high estimate and 1·7 percent by low estimate, by the turn of century. By that time the total population of the country would have reached as high as 175 million or as low as 140 million. This is a staggering figure considering the present population of 75 million which the country has difficulty in feeding. A population graph based on the author's estimate is given in fig.2. So it is doubtful that in next twentyfive years the standard of living enjoyed by the people will show any improvement.

1.3.1. Bangladesh is among the most crowded corners of the world. It is probably most densely populated among the countries that are dependent on agriculture. Present population of the country is 75 million. Density Of population per square mile is 1,361. The density distribution follows the pattern of intensity of cultivation of agricultural land. Bangalees as a race is referred to as an admixer of Tibeto-Mongolian and Dravido-Aryan stock. About 85 percent of the population are Muslims. Buddhists, Hindus and Christians constitute the rest. Over all percentage of literacy in the country is only 22. (4)

1.3.2. Like all other developing countries Bangladesh demonestrates a broad population pyramid (fig.3). Half the population is under 15 years of age. Consequently a vast majority is inactive population, consisting of children, elderly people and woman. Women are discouraged in their free movement and participation in wage earning activity because of the Muslim custom of 'Purdah'.

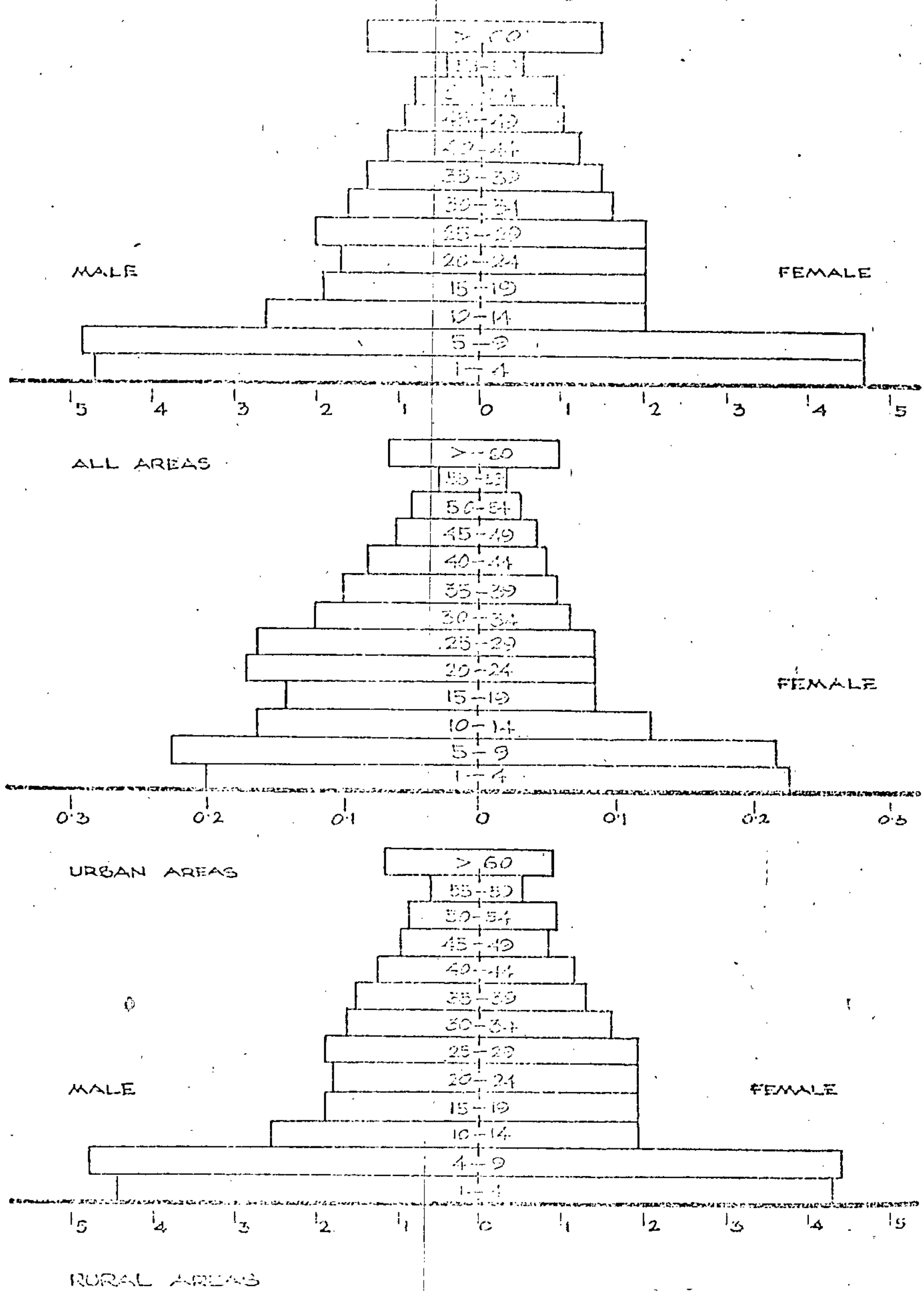

Fig. 3. Population pyramids in both rural and urban areas (5)

1.4.0. URBANISATION

Bangladesh is one of the least urbanised countries in the world. In respect of urbanisation it is well behind countries like India, Srilanka, Burma, Indonesia and Thailand. Number of towns and their population according to 1961 cencus have been shown below. (fig.1.)

POPULATION OVER	100,000	4
	50,000	5
	25,000	15
	10,000	23
	5,000	21

According to census definition places with 5,000 or more inhabitants were considered towns. (5)

1.4.1. The low percentage of urbanisation is because people are mostly dependent on agriculture for their livelyhood. Industrialisation has been very little. Total labour force employed in industries is 400,000 only. (7) Low key economic activity do not create enough employment opportunity for people to migrate to cities. Considering the present rate of economic growth it is expected that the trend of urbanisation will remain as it is now, for some time to come. But this does not mean that the cities do not have problems. Though the percentage of total population coming to town is very low, the number of people for whom services are to be provided is substantial and pose a serious problem.

1.4.2. Urbanisation in Bangladesh has taken place primarily due to the following reasons.

A. Employment opportinities in cities.

B. Attraction of city life.

C. Increase in education. Literate people develop a notion that they are too smart to live in rural areas.

D. Influx of Muslim refugees from India in 1947.

E. Repatriation in 1973; 1·5 million people came back to Bangladesh from Pakistan and most of them setteled in towns.

F. Sub subsistance level of agriculture; when the land can not sustain any more population people turn towards cities and settle mostly in squatter areas. Every natural calamity is associated with influx of population to the cities.

There is however nothing wrong with low rate of migration. As a matter of fact it creates less problem. There is no advantage in over crowding the existing cities. But efforts should be made to provide services and to raise the standard of living of the people in villages. Labour intensive small scale industries following the ideas of intermidiate technology seems to be the answer.

1.4.3. It is interesting to note that in Bangladesh there is a clear imbalance in the sex and age ratios of the urban population. Urbanisation is largely a matter of migration by the males of the economically active age group between 20 and 40. These males migrate withuot their wives and families. The age and sex pyramids for urban and rural population is shown in fig.3. In five largest cities there are between 532 and 676 females per thousand males. In the capital city of Dacca the number is 607. Bangladesh as a whole, 27 percent of the population is in the age group of 20 to 39.

In the major cities this age group constitutes a much higher proportion; 33 percent in Khulna, 37 percent in Chittagong and 35 percent in Dacca. These figures lead one to think whether some housing, specially industrial housing should be designed as hostels; where only men will live without families. Percentage of population living in towns at various times are; 2·7 percent in 1931, 3·3 percent in 1941, 4·4 percent in 1951, 5·2 percent in 1961 and 8 percent to-day. (fig.2.) (5)

1.5.0. CLIMATE

Climate as defined by Koenisberger is " an intigration in time of the physical states of the atmospheric environment, charact- - eristic of a certain geographical location." * According to the classification of the global tropical climate suggested by G,A,. Atkinson (1) climate of Bangladesh may be called Warm-Humid equitorial climate. It has also been called Tropical Monsoon climate, which seems to be more appropiate.

1.5.1. The maximum temperature is attained in April contrary to the general belief that May is the hottest month of the year. (6) Summer maximums generally range between 91°F and 96°F. Only in very rare cases three figures are registered. In summer temperature hardly goes below 70°F. The greatest range in summer temperature is found in North Bengal; about 24°F. The highest temperature of April and May is followed by slight decrease in June - August and then another rise in September and October.

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* Koenisberger, O.H. et al "Manual Of Tropical Housing And Building" P. 3

	J	F	M	A	M	J	J	A	S	O	N	D
MEAN MONTHLY MAX. °C	24	26	32	34	33	32	32	32	32	31	28	24
MEAN MONTHLY MIN. °C	9	12	16	21	23	25	26	26	26	22	16	11

Mean monthly temperatures of DINAJPUR

MEAN MONTHLY MAX. °C	26	28	31	32	32	31	30	30	31	31	29	26
MEAN MONTHLY MIN. °C	13	15	19	23	24	25	25	24	24	23	19	14

Mean monthly temperatures of CHITTAGONG

Table. 1a.

	J	F	M	A	M	J	J	A	S	O	N	D
MEAN MONTHLY MAX. °C	25·1	27·6	32·1	33·6	32·8	31·8	31·0	31·0	31·5	31·2	28·3	26·4
MEAN MONTHLY MIN. °C	13·0	15·0	20·0	23·4	24·4	25·6	26·0	26·0	26·0	24·0	16·9	14·2

Mean monthly temperatures of DACCA

ABSOLUTE MAX. °C	31·1	34·5	33·9	40·5	38·4	36·6	35·0	35·5	36·6	35·0	34·5	30·5
ABSOLUTE MIN. °C	7·2	6·7	10·5	16·6	14·5	19·5	26·6	27·2	26·6	18·4	12·2	8·9

Absolute temperatures of Dacca

Table 1b.

CLIMATIC DATA FOR DACCA

TEMPERATURE

	J	F	M	A	M	J	J	A	S	O	N	D
MEAN AIR TEMP °F	66.7	70.4	79.0	83.2	83.5	83.7	83.6	83.3	83.8	81.8	75.0	68.0
MEAN DIURNAL RANGE °F	22.4	22.7	21.7	18.4	15.3	11.1	9.3	9.0	9.9	12.9	17.8	21.0
ABSOLUTE MAX. TEMP °F	88	94	102	105	101	98	95	96	98	95	94	87
ABSOLUTE MIN. TEMP °F	45	44	51	62	58	67	70	71	70	65	54	48

RELATIVE HUMIDITY

9 A.M PERCENTAGE	80	76	76	78	79	86	87	87	84	80	78	82
6 P.M. PERCENTAGE	53	50	45	52	73	78	79	78	78	73	66	64

OTHER DATA

MEAN MONTHLY RAINFALL/INCH	.32	1.24	2.39	5.40	9.64	12.39	12.97	13.26	9.76	5.27	0.95	0.20
HEAVIEST RAINFALL IN 24HOURS/INCH	1.82	2.90	5.25	4.82	5.10	7.29	9.26	8.16	7.00	7.80	7.08	1.75
MEAN NO. OF RAINY DAYS	0.8	1.9	3.2	6.7	11.0	14.5	17.7	17.6	12.1	6.0	1.3	0.4
WIND SPEED IN KNOTS	1.3	1.8	3.2	4.7	4.5	4.9	5.1	4.6	3.3	1.7	1.2	1.2

Table.2.

January is the coldest month of the year. A short winter lasts from end of November to middle of February. Winter temperature hardly goes below 50°F. Diurnal range of temperature during summer months is small. For Dacca the average of summer months is 14°F. In coldest months diurnal range rarely exceeds 30°F. Winter days are very pleasant, characterised by clear sky and bright sunshine. Considering two extreme points, one Chittagong at the coast and other Dinajpur about 250 miles inside from the coast, we find that absolute minimum in Chittagong is 7°C and and in Dinajpur 3·6°C. Absolute maximum in Chittagong is 38°C and in Dinajpur 40°C. Table 1a shows the temperatures of these two places.

1.5.2. The rainfall map (fig.4) indicates the total annual rainfall of the region. It varies from 60 inches (1500m.m.) in the West to 120 inches (3000m.m.) in Sylhet and Southern Chittagong. But the rainfall regime is remarkably similar throughout the country. The April - May period is known as 'chota barsat' or little rains. Rainy season or the monsoon generally signifies the rain from June to September. Intense rain may fall for a relaively short period of time; 20 inches of rain have been reported for a 48 hr. period of time. Agriculture is very much tied up with rainfall and hence the economy but ironically rainfall in the months from March - May and again from September to October, rather than the total determine the fortune of the agriculturalist.

1.5.3. Bangladesh is characterised by light winds, except for occassional storms. In winter the wind is mostly North and North-West

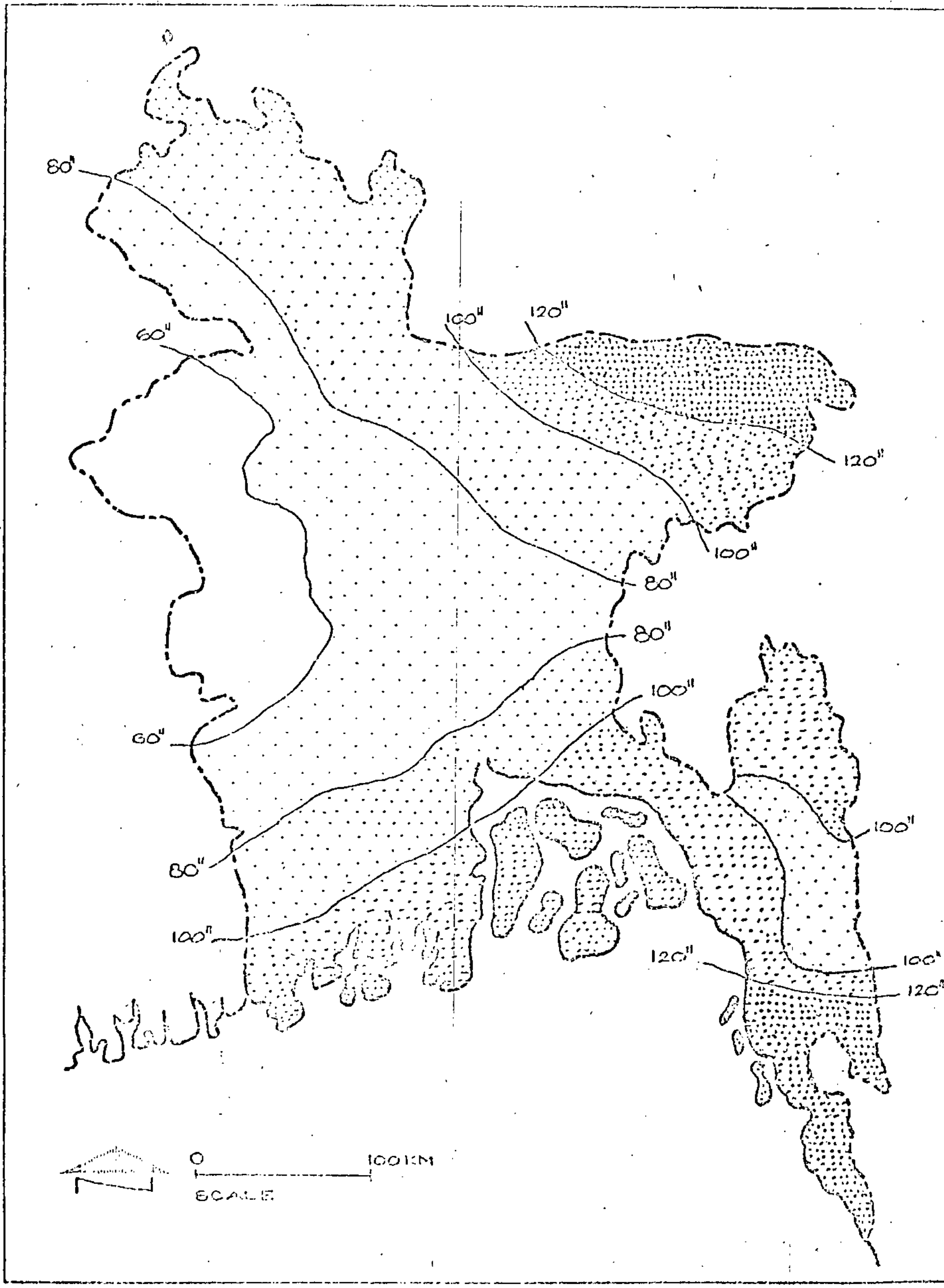


Fig. 4. Mean annual rainfall in inches.

and the velocity does not exceed 1 to 2 miles per hr. in most parts. In the Southern coastal areas wind speed ranges from 2 to 4 miles per hr.. During the typical monsoon months the wind direction is South, South-East. In North Bengal the Easterly winds are more frequent. Wind velocity all over the country at this time is generally higher tean the rest of the year.

1.5.4. Bangladesh is often victim of severe storms. The pre-monsoon months of March to May are characterised by violent thunder storms called Nor'wester, locally known as "Kal Baisakhi". Thunder storms are often accompanied by frequent air to air electric discharge. Strong local winds occassionally occuring as tornadoes can cause damage to the frailly structured Bengali home-stead. This is sometimes associated with hail storms. Most usual time of occurance of Nor'wester is between 5 p.m. and 8 p.m. But sometimes it continues throughout the night. The height of the base of the cloud during this time may be 500 ft. or less. The thickness of thunder cloud may be at times 2,000 ft. Both vertical and horizontal [illegible] visibility is bad during the storm. Flood and cyclones are two natural hazards that hit Bangladesh almost every year. The two seasons for cyclones are April - May and October - November. Wind velocities rainging 100 - 150 miles per hr. have been recorded. These cause wide spread devastation. The worst so far took place on 12 th. November 1969.

1.5.5. Humidity in Bangladesh is generally high through out the year. In winter months relative humidity varies 70 to 80 percent. The months of June-July are most humid with percentages 80 to 90. In September and October Humidity is also above 80 percent.

The humidity with high temperature make these the months of sticky heat. (6) A climatic chart for Dacca is shown on fig.5.

1.5.6. The skies are clear in the months of November - January. For most of the rainy season cloudy conditions prevail. Skies are very bright in Bangladesh; a luminance of 7000 cd/m². It may be even more when the sky is thinly overcast. When heavily overcast sky is dull; luminance less than 800 cd/m². Sometimes visibility decreases substantially. The sunshine hours for Dacca are shown in fig.5.

1.5.7. Pressure is minimum during June-July away from the sea. Lowest pressure is recorded in Dinajpur 996·4 m.b., Bogra 998·6 m.b., Mymensing 999·0 m.b.. After that pressure gradually rises. In January lowest pressure reading is in Dinajpur 1012·8 m.b., Bogra 1015·1 m.b..

1.5.8. Solar radiation is partly reflected and partly scattered by the cloud cover and the high vapour content of the atmosphere. Radiation reaching the ground is diffused but strong and causes painful sky glare. Cloud and vapour content reduces outgoing radiation from the earth, thus in summer accumulated heat is not readily dissipated. However downpour of rain reduces the temperature to a degree.

1.5.9. Rainfall, temperature, humidity and soil condition are all favourable for the abundant growth of vegitation. Lush green luxuriant vegitation grow profusely in Bangladesh. Control of unwanted vegitation poses problem. Subsoil water table is quite high specially during rainy seasons. Organic building materials decay quickly. Algal and fungal growth on buildings are frequent. Rusting and rotting is also accelerated by high humidity all over the country.

1.5.10. Abundant dust is carried by the wind during winter months. Mosquitoes and other insects cause menace all through the year. Termite is a dangerous enemy of buildings, specially when built with indegeneous building materials. Bengali calander shows six seasons in the year. But strictly speaking there are four seasons viz. winter, spring, summer and monsoon.

1.6.0. HOUSING SITUATION

As stated before 92 percent of the people in Bangladesh live in rural areas. Rural housing in Bangladesh is not an organised activity. It is entirely left to the individual, that is private sector. Hardly any services are there. Houses are built of local indegeneous materials with rudimentary technology. Homesteads are usually raised above the flood level in the form of a earthen mound. Earth is taken from a borrow pit which later turns into a pond. The pond supplies water (other than drinking) and is used for culture of fish. The home-stead always have a large number of trees. So much so that from a distance it looks like a grove. The trees are usually fruit trees. Trees stop erosion, provide enough shade and reasonably modifies the micro-climate. The houses are built around an open space usually on four sides clearly defining the central court, which is a multi-purpose area used for all outdoor activites, viz. children play area, drying food grains, etc. . This is a semi private area. The pond, plants, open spaces all together seem to maintain a perfect ecological balance. The houses are for extended families involving three sometimes four generations. Different blocks on different sides of the open space are used for different functions. Ones on the North and South are usually used for sleeping.

1.6.1. The home-steads are so far apart that it makes any provision for services in future almost impossible. Presently home-steads are encroaching on agricultural land which need to be stopped. Efforts should be made to provide some services like drinking water (a tubewell for a few families), road and communication network, etc. . So efforts are being made to make some sort of regulations possible in a rural situation. Nucleated village form seems to be a very good idea. But it is argued if significant saving in land will be made. If it will be worthwhile to disturb the present pattern which is scattered. Because it will need tremendous effort to move the people from their present locations and bring them together. If density is increased without proper provision for services like waste disposal, pollution may become a serious problem and might disturb the natural ecological balance. However some sort of order should be tried to be brought in for the new home-steads and expansion of old ones. Some sort of local planning organisation should be incorporated along with other government administrative bodies.

Though the condition of houses in the rural areas are far from satisfactory, it is better than the urban situation. Poverty seems to be less conspicuous in rural areas than in urban areas.

1.6.2. Urban housing in Bangladesh is at a deplorable state. Like in most other developing countries shortage is acute and supply is far less than the demand. In an urban situation a wage-earner has to spend a major share of his income, sometimes up to 50 percent for housing, which is not up to the standard by any definition. Housing activities are limited to private sector at an individual level. Development of organised housing for large groups is limited to a few government ventures only. Govt. employees sometimes get a flat for a small percentage of income as rent. The rent is usually between 7·5 and 15 percent of ones salary. These houses are highly subsidised so much so that sometimes the rent do not even cover the maintenance cost of the flats. The flats are of various types starting from a minimum of 400 sq. ft. to about 3,000 sq. ft. . The allocation of types of housing is strictly according to income and status of the employee and not according to needs or family sizes. Semi govt. autonomous bodies like banks, universities, etc. sometimes have housing for their own staff members. But number of houses in no case is adequate specially for the lower income groups.

In the appendix a few histograms have been shown. 1st. one shows the income groups. By far the largest number belongs to the lowest income group. Only one percent belong to the upper class. The 2nd. one show the family sizes according to income groups.

The third, fourth and fifth ones show the distribution of various available facilities according to income groups. Classification of house types are usually made depending on the material and type of construction. These are;

A. All pucca (pucca roughly means masonry construction)

B. Floor and wall pucca (roof is of c.i. sheet)

C. Floor pucca, wall and roof tin (c.i. sheet)

D. Floor and wall kutcha (kutcha means temporary materials like mud, bamboo, thatch, etc.)

E. Floor, wall and roof kutcha

This classification is mainly according to cost and aspirations of the people. This is not according to comfort condition or performance of the buildings. This is associated with the prestige (status symbol) of the inhabitants which plays such an important part in developing countries. On a national basis 57 percent of the urban houses are owner occupied and rest are rented. Of the owned accomodation 52 percent are inherited, 36 percent are bought and only 12 percent are built by the owners.

Rates or taxes for property is very nominal. Taxes are not sufficient to support the services. So local authorities or munucipalities do not have enough money to build new houses. Some of the services like water supply, electricity, communication, etc. are under direct control of the centre. This means all urban housing is indirectly subsidised. Private housing societies are not common. Four major cities have loan giving agencies for housing. It is also possible for an individual to get loans from the bank. But loan giving facilities are limited to upper classes only. However investment in housing is considered a very sound one by all groups.

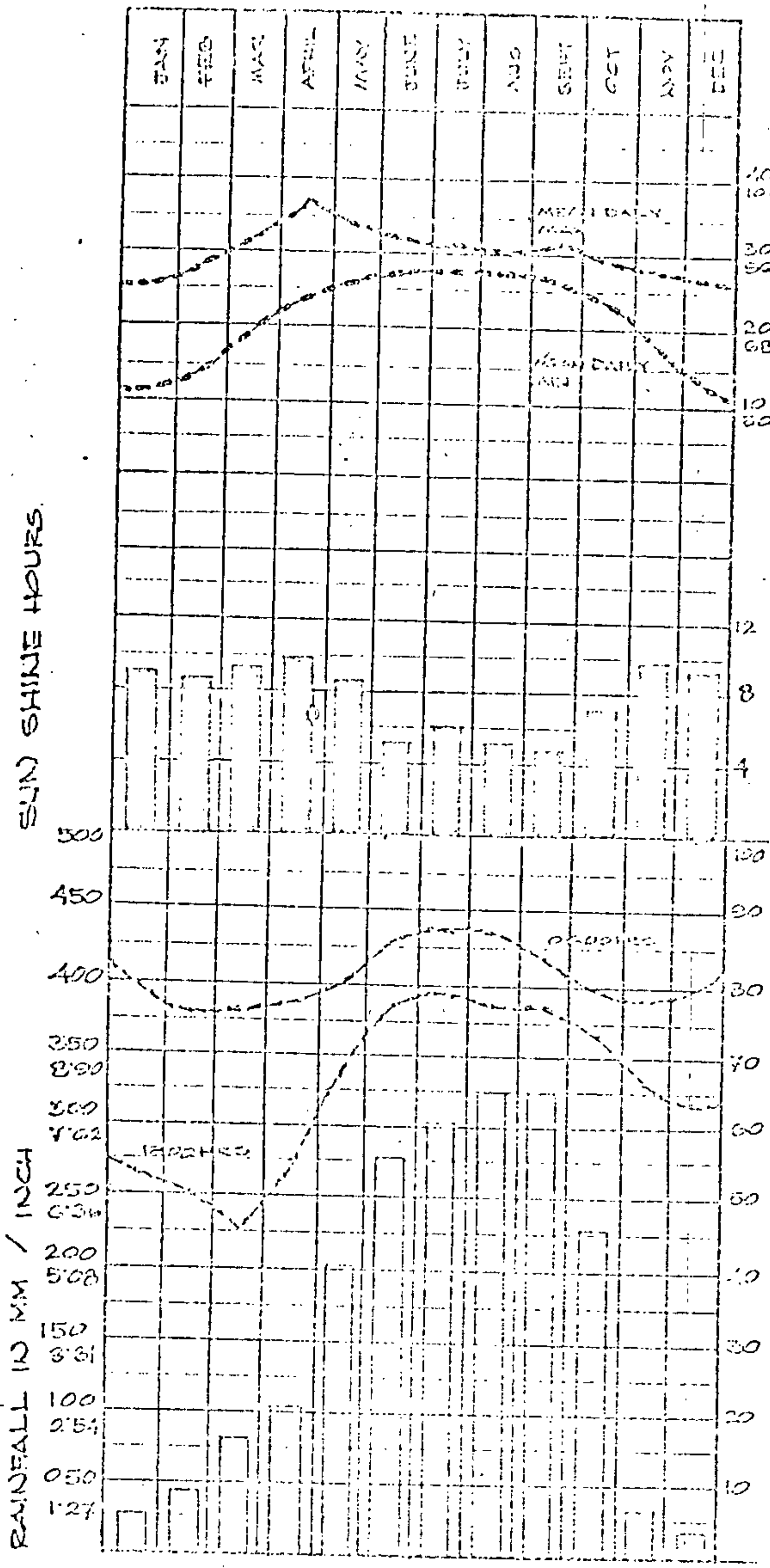
1.6.7. Water supply from treatment plants are inadequate. But ground water is available almost everywhere, Deep tubewells have become a convinient source of water supply. Water is pumped to high storage tank and supplied from there without any disinfection. Despite of hot humid weather domestic consumption rate is quite low. Possibly because of paucity of supply. A sewer system exist in some towns but capacities are quite inadequate. Night soil collection system exist in all towns. Most of the new houses have septic tanks. Hydro electricity from Kaptai dam supply to most of the South-Eastern parts of the country. Thermal power stations supply to other cities. Electricity is relatively cheaper compared to waster countries. Natural gas is available for cooking in some cities mainly in South-Eastern parts of the country. In other parts fire wood is primarily used. There is good railway connections between cities. Bus service between cities are also common. Only four cities have internal bus service within the city. Cycle rickshaw is the main means of public transportation in most of the cities including Dacca.

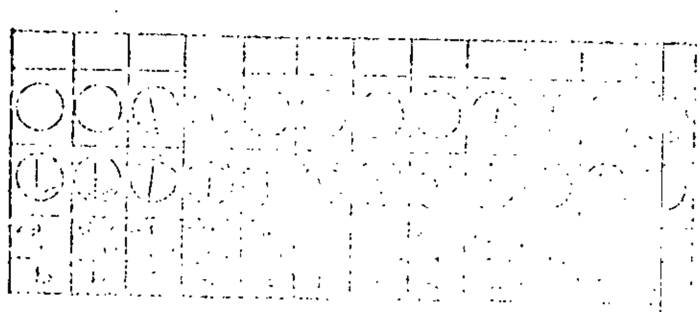
1.7.0. DACCA, CAPITAL CITY

Historians belive Dacca to have existed as an urban centre as far back as third and fourth century A.D, During Hindu rule seat of the ruler was at 'Sonargaon' about thirty miles ... from Dacca. Even at that time Dacca was known as the place of

'Bahanna Bazar Teppanna Gali', meaning fifty two markets and fifty three lanes. Before the Mughals, in the twelfth and thirteenth centuries Dacca had been recorded as a prominent business centre of the East. In 1608 Mughal viceroy Islam Khan chose Dacca to be the capital of Bengal. He did so primarily for defense reasons. It is at the bank of river Buriganga commanding strategic importance. It remained capital for about one hundred years till 1706. This is probably the glorious period of Dacca. During this time trade and commerce flourished and population increased; according to some estimates up to one million. It is supposed that city limits extended up to Tungi. 1706 onwards Dacca experienced a decline. In 1756 after the establishment of British rule Calcutta, a sea port on the bank of river Hoogly, gained prominance and Dacca lost all prominance. To boost the morale of the backward Muslim peseants; Assam and East bengal was united into one province by the British rulers, with Dacca as its capital, in 1907. This remained the capital up to 1912 when East and West Bengal was reunited due to political reasons. Most of the big historical buildings dates back to that period. In 1947 after indipendence Dacca became the capital of East pakistan. Dacca gained prominance again. Population increased associated with building activity. Most of the modern structures, including govt. housing, were constructed during that period. In 1971 Dacca became the national capital and primary city of Bangladesh.

1.7.1. The climatic data for Dacca is given in table 1.b. and 2. This is from the meteriological department. Micro climate may vary a great deal from the data supplied. Microclimate is generally affected by topography, ground surface, three dimensional object, proximity of water body, etc. Dacca is flat without any raised part or hills. So the question of slope of the ground in relation to wind direction and solar radiation do not arise. But man made objects like buildings and changed surface qualities do play their part. Roads of Dacca are mostly water bound macadam road with black bituminous surface. Paved surfaces and buildings in cities reduce evaporation. So air temperature gets higher than the surrounding country side. Koenisberger suggests that in some cases the difference between city and country air may be as high as 8 to 11° C. He also adds that quick run off absence of vegitation and higher temperature may reduce the humidity by 5 to 10 percent. (12) This would be an advantage for Dacca. Wind velocities at the ground level is less and the velocity is increased as the height from the ground increases. Velocity near the ground is further decreased by buildings and vegitation. [illegible]. Wind speed may decrease after a low horizontal barrier by 50 percent at a distance of ten times the height of the building. (12) Dacca is surrounded by low lying areas which makes a large water body during the rains. Many parts of the city experience standing water, sometimes for days together at the time of heavy down pour. This cause dampness and increase in humidity adding to the discomfort. But the temperature is possibly reduced a little by





COUNTRY BANGLADESH
LOCATION DACCA
ALTITUDE 7M 23FT.
LATITUDE 24°N
LONGITUDE 90'6E OF GR

SUN ALTITUDES FOR DACCA

TIME	DEC22	MAR21 SEP23	JUNE
12	43°5°	66'5°	89·5°
11&13	41'0°	62'5°	76'0°
10&14	35'0°	53'0°	61'5°
09&15	22'0°	40'0°	48'5°

ABSOLUTE MAXIMUM TEMPERATURE IS 105°F
ABSOLUTE MINIMUM TEMPERATURE IS 44°F
MAXIMUM DURNAL RANGE IS 22.7°F AND OCCURS BETWEEN DECEMBER AND FEBRUARY
SEVERE STORM MAY OCCOUR IN SEPTEMBER AND OCTOBER AND ALSO IN MARCH AND APRIL
STORMS USUALLY OCCUR DURING THE AFTERNOON
RAINS ARE SOMETIMES ASSOCIATED WITH GUSTY WIND.

(3)

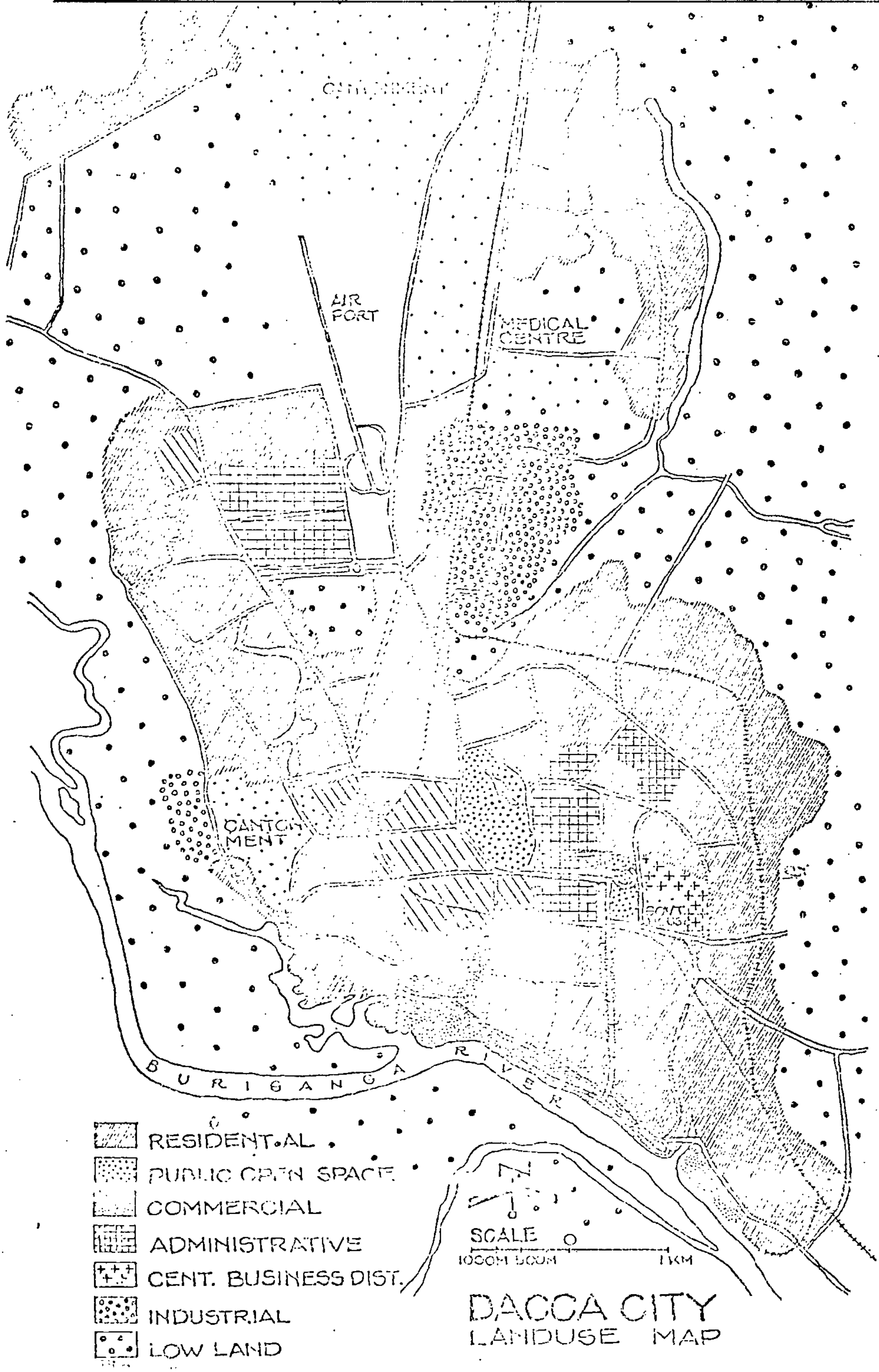
Fig. 5, Climatic chart for Dacca.

the continuous rains. There is no serious industrial air pollution in Dacca. Fire wood used for cooking give rise to smoke. This intensifies the fog during winter specially in the evening. In winter dust causes considerable annoyance. Thunder storms often occur and is associated by electric discharge. Buildings specially higher ones must be protected by lightning arresters. Dacca is in semi earthquake zone. Structures specially high ones should take this factor in to consideration.

1.7.2. Population of Dacca has greatly varied through out history. In the seventeenth century it is estimated that population of Dacca was about one million. It was 200,000 in 1765; 68,000 in 1765; 153,000 in 1911; 213,000 in 1941; 336,000 in 1951; and 550,000 in 1961. There seem to be some controvarsy about the exact present population of Dacca, Guesses vary from 1•2 million to 2 million. A conservative assumption would be 1•5 million. It can be safely assumed that more than 0•4 million people live in squatter settlements. Number of tax paying households in Dacca at different times are given below. (3)

Year	Population	Number of households
1947	250,000	20,482
1951	336,000	? 20,355
1961	550,000	44,604
1971	1000,000	51,431
1973	1200,000	53,546

An estimate of number of rooms in relation to population


AIR PORT
MEDICAL CENTRE
CANTON MENT
BURIGANGA RIVER
RESIDENTIAL
PUBLIC OPEN SPACE
COMMERCIAL
ADMINISTRATIVE
CENT. BUSINESS DIST.
INDUSTRIAL
LOW LAND
SCALE
1KM
DACCA CITY
LANDUSE MAP

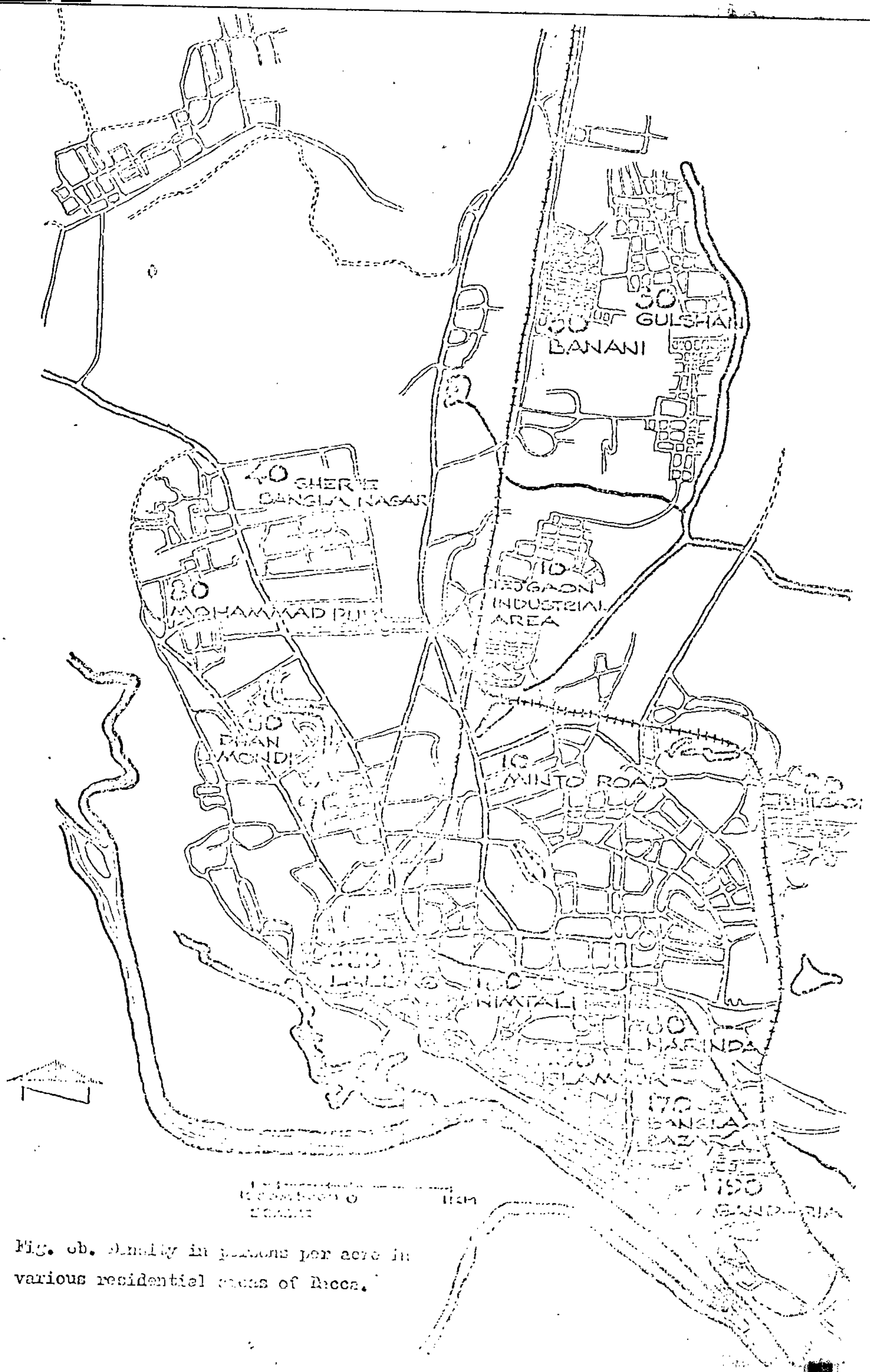


Fig. 6b. Density in persons per acre in various residential areas of Dacca.

would possibly give a clearer picture than number of houses. However these figures are enough to indicate the extent of housing shortage. Within the quarter of a century under consideration the population of Dacca increased by 950,000 and the number of houses increased by 33,000. Of these 9,546 were built by the govt. through various agencies. A break down of the agencies are given below. (3)

Various govt. departments	6,242
Dacca improvement trust	223
Bangladesh railways	870
Telegraph and telephone dept.	517
University of Dacca	428
Nationalised banks	258
Miscceleneous	1,000

In the first five year plan Bangladesh govt. has a target of building 35,000 houses at an approximate cost of 2000 million takas in allthe urban areas of the country. Though very inadquate considering the need, this is an appriciable step and an ambitious target.

1.7.3. Price of land in the city of Dacca is increasing at a very fast rate. Between 1962 and '72 price of land has increased by more than 250 percent. The city is expanding towards the North in a rather disorganised manner. But the land inside the existing city limits are not being used very judiciously. Though there is enough pressure of population and tremendous increase in price of land, such unused land or uneconomically used land may be found in and around the core. This seem to defy the economic principles. Suburban types of detached houses have been built on large tracts of land by the higher income group of people very close to the central business district. This seem to have been encouraged by the earlier governments. Because these land were developed by Dacca Improvement Trust and devided in to plots and were sold to higher income group of people. Dhanmondi, Gulshan and Banani are such examples. Gross density of these areas are abuot 30 persons per acre. Except for areas in old Dacca near the river, density in other areas seem to be very low. A landuse map of the city is shown in fig.6a.Densities of various areas are given in fig.6b. Case study materials of the govt. housing at Azimpur, is given in Appendix 2. The Azimpur area with three storey flats have a density of about 80 persons per acre. It seems that descisions to make three storey flats were not made to obtain greater density. Because it is possible to obtain similar densities with one storey houses. It was done possibly because three storey flats were considered more prestigous.

CHAPTER TWO CHAPTER TWO

2.1.0. Macfarlane and others defined comfort " As certain thermal conditions in which over 50 percent of the people are unaware of their climatic environment - that is they do not feel the need to adjust to it. "* Thermal comfort has been defined by some in a negative sense as absence of irritation and discomfort. P.o.Fanger has defined thermal comfort as " That condition of mind which expresses satisfaction with the thermal condition."**

2.1.1. Thermal comfort is not same as thermal balance. Thermal balance is essential for comfort but can also be obtained under conditions of discomfort. Thermal comfort do not also imply that thermal conditions should be kept constantly at a very precise level. Thermoregulatory systems can achive comfort within a given set of conditions or zone known as comfort zone. Some fluctuations in indoor conditions such as temperature and particularly air velocity, are rather helpful. This prevents monotony and have an invigorating effect on thermoregulatory system.

2.1.2. If a group of people is subject to the same room climate, it will not be equally pleasing to everyone. So it is not possible to satisfy everyone at the same time. The objective is to create optimal thermal comfort for the group. That is to create an

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* Macfarlane, J.W. et al "Thermal Comfort Zones" Architectural Science Review, Vol.1, No.1. 1958

** Fanger, P.O. "Thermal Comfort", Danish Technical Press, Copenhagen 1970 P.15.

environment in which highest possible percentage of the group is in thermal comfort.

2.1.3. Usually it is possible to determine with considerable accuracy the conditions of pleasantness and comfort. It is more difficult to estimate the degree of discomfort. A scale is necessary for the assesment of the degree of severity of the thermal sensation. The author prefers the Bedford's scale of warmth. The scale may be numbered as; (23)

1	Much too cool
2	Too cool
3	Comfortably cool
4	Comfortable
5	Comfortably warm
6	Too warm
7	Much too warm

Assesments 3, 4 and 5 indicates thermal comfort or absence of discomfort due to warmth or to coolness. Assesments 6 and 7, imply discomfort due to warmth and 1 and 2, discomfort due to coolness.

2.1.4. Many factors contribute to the feeling of comfort. These are both subjective and objective. The objective factors are;

Air temperature and mean radiant temperature,

Relative humidity, vapour pressure in ambient air and precipitation

Air velocity and air pollution,

Solar radiation and glare,

Metabolic heat production and activity level,

Clothing.

The subjective factors are; national and geographic location, age, sex, body build, skin colour, food, circadian rythm, ethonic group, etc.

Besides these there are various other environmental and psychological factors that influence the comfort and pleasantness of the environment. B.S.Saini says "Factors such as the size proportion, character and surroundings of rooms, the colour-scheme and even the views from the window have a great psychological effect. There is the combined effect of sun, fresh air and greenery which impinge on man's higher nervous activity, providing favourable sense impressions during periods of physical activity and rest."*

2.2.0. OBJECTIVE FACTORS

2.2.1. Air velocity: Air velocity affects the human body in two different ways;

A. It determines the convective heat exchange of the body and environment. The effect of air velocity and air temperature on convective heat exchange is inter-related.

B. It affects the evaporative capacity of air and consequently the efficiency of cooling. The effect of air velocity on the evaporative capacity is inter-related with the effect of humidity.

* Saini, B.S. " Building Environment."
Sydney, Angus Robertson in association with RAIA.

When the air temperature is below skin temperature, air velocity will help both convective and evaporative cooling and cooling effect increases as air temperature is lowered, When the air temperature is above the skin temperature, increase in air velocity causes higher convective heat exchange and warms the body. But on the other hand an increase in air velocity increases the evaporative capacity and hence the cooling efficiency.

When the skin is wet and the cooling efficiency of sweating is below 100 percent an increase in air velocity affects the sweating efficiency more than it does convective heating. So air velocity reduces both sweat rate and subjective discomfort due to wet skin. Effect of air velocity continues as long as the skin is dry. Further increase in air velocity do not cause any more evaporative cooling but convective heat effect continues. From this it is evident that at high air temperature there is an optimum value of the air velocity. The optimum velocity is not constant but depends on the temperature, humidity, metabolic level and clothing. At 40°C, 30mm Hg vapour pressure, metabolic rate 200 Kcal/h the optimum velocity is about 100 cm/sec. (15)

2.2.2. Clothing: Clothing acts as a barrier to both convective and radiative heat exchange between the body and its environment and interferes with the process of sweat evaporation. It also reduces the sensitivity of the body to variations in air velocity and temperature. At air temperature below 35°C it always reduces the rate of dry heat loss from the body. On the other hand at air temperatures above 35°C it reduces heat gain from the environment. It also reduces the cooling efficiency of evaporation because most of the evaporation take place from the clothes. The air velocity over the skin is also reduced.

Thermal resistance provided by clothing depends not only on the fabrics but also on the stiffness and fit of the garment. The unit is 'clo'. Normal business suit and cotton underwear is 1 clo. and heaviest arctic clothing is 4·5 clo. When a man is exposed to solar radiation his clothing reducesthe solar heat gain. As clothing reduces evaporative cooling efficiency, in high humidity specially under working coditions when sweat is increased, it may have adverse physiological effect resulting in a increse in the heat stress.

Except for black, colour of the clothing has apparently little effect on protection from solar radiation. Interaction between the effects of wind speed and clothing depends on the air permeability of the clothes.

2.2.3. Humidity: Humidity of air may be expressed in various ways. These are Relative Humidity (percentage), Absolute Humidity (g/kg or g/m), Specific Humidity and Vapour Pressure (N/m^2 or millibar). Humidity do not directly effect the heat load operating on the body. Evaporative capacity of the air and hence the cooling efficiency of sweating depend on the humidity.

In warm damp condition the vapour pressure gives the most useful expression of humidity conditions than the relative humidity. Givoni(15) gives an example to explain the situation. A relative humidity of 100 percent at an air temp. of 25°C corresponds to a vapour pressure of 24mm Hg. while the skin v.p. is about 37mm Hg. The air in contact with the skin is to 31° - 32°C and its r.h. is lowered accordingly allowing evaporation to take place. But a r.h. of 50 percent when the air temp. is 50°C corresponds to a v.p. of 46mm Hg. or approximately the v.p. of the skin which is at a lower temp. than the air. under such conditions evaporation from the skin is impossible.

At higher temperatures the influence of humidity on the responses become more apparent specially on skin wetness, skin temp. and sweat rate. When all the sweat from the skin is evaporated the cooling efficiency is 100 percent, But as the evaporative capacity of air reaches a point when all the sweat cannot be evaporated discomfort is caused by moist skin. Then sweat is absorbed by the clothing and is evaporated from there. This means some of the heat for evaporation is taken from the surrounding air rather than skin. This reduces evaporative cooling efficiency. The body has to secrete more sweat than that equivalant to required cooling.

2.2.4. Metabolic heat: Human body continuously produces heat through the process of metabolism. Only 20 percent of the energy produced is utilised in the body, remaining 80 percent of the heat is to be dessipated to the environment. The body releases heat to the environment by convection(C), radiation(R) and evaporation(E). Heat exchange with the surrounding take place according to the formula;

$$M \pm R \pm C - E = Q$$

M is metabolic heat and Q is the change in the heat content of the body. Deep body temperature remains balanced and constant around 37° C. Metabolic heat produced depend greatly on the activity performed. It may vary from a minimum of 70 watts when a person is sleeping to a maximum of 1100 watts when the person is doing heavy work continuously for a considerable time. In warm climates as over heating continues sweating starts. Sweating may vary from about 20 g/hr. to 3 kg/hr. depending on physical effort and environmental effects.

2.2.5. Air temperature and Mean radiant temperature: Temperature causes heat exchange of the body by radiation and convection. This heat exchange greatly depends on air velocity and clothing. When air velocity and vapour pressure is constant a rise in air temp. results in the increase of skin temp. and sweat rate. The increase is dependent on existing air velocity and humidity. Macpherson, et al suggest that an increase in M.R.T. of 1° deg. C elevated the sweat rate by 11 g/hr. and rectal temp by •005° deg. C Houghton, et al found that, on average, an increase of 1° deg. C in the M.R.T. will increase the E.T. by 0•5° deg. C and air temp. by 0.5° deg. C. (15)

2.3.0. SUBJECTIVE FACTORS

Subjective factors affect the feeling of comfort. The effects of factorswill be considered in the following paragraph. It is up to the designer to incorporate various factors in creating a psychologically pleasing environment. The effect of subjective factors are sometimes overemphasised.

It is observed that subjective factors change the physical comfort conditions of the environment by a very small magnitude. As a matter of fact when any difference in comfort level do exist due to subjective factors, it is usually small and do not alarm much engineering significance. However factors like necessity of large intake of water by people in hot humid climate can not be over estimated. Subjective factors have great psychological importance. The influence of the colour scheme of the of the environment or view outside say, green lawn as opposed to bare sandy patch, can not be over emphasised.

2.3.1. National geographic location: Acclimatization to heat is a well established phenomenon. When a person accustomed to live in a cool climate is suddenly transferred to a hot climate a series of physiological adjustment will occur in him. These adjustment ameliorate the physiological strain experienced on the initial exposure to heat. Just after exposure to heat ability to do is impaired and high degree of subjective discomfort occur. It takes about 30 days to reach full adjustment in a changed environment. The acclimatization depends first and foremost on an increased ability for maximal sweating. Although persons living in the tropics can better endure hot environments and have become used to accepting discomfort due to heat, this seem to have only slight influence on the thermal environment which they will prefer, if given a choice. Fanger's (22) study between Danish and American samples and Ellis's study of Chinese and Western subject(17) go on to prove that no significant difference in comfort conditions exist between persons of different national geographic location.

2.3.2. Age: There seem to exist a difference in comfort conditions between yong age persons and elderly persons. But the difference becomes significant when groups of very old age, say a group with average age of 75 is considered. One of the reasons for is probably because the activity level of elderly people is low hence they prefer a slightly warmer environment. There is no difference in comfort condition between boys and adults. But data on children specially pre school children were not available.

2.3.3. Sex: Females generally prefer warmer environment than males. The degree of variation seem to have been different in different studies. It varies from 0·5°C to 1°C. The difference might have been due to differences in clothing. Women also have a slightly slower metabolic rates than men. They also have a slightly lower insensible perspiration.(22)

2.3.4. Body build: It is popularly belived that obese persons prefer cooler environment than persons of slighter build. Fanger's study show that among college age subjects fat groups prefer a temp. approximately 0·2°C lower than thin groups. So he concludes that there is no significant influence of body build on comfort conditions of sedentary subjects.

2.3.5. Intake of food : Intake of food causes a certain increase in internal heat production. This is expected [illegible] to have an influence on thermal comfort. The increase is highest for protein, substantially lower for carbohydrates and smallest for fat. This is important in Bangladesh situation because food is usually taken in the kitchen which is warmer than other rooms because of more heat production; windows are smaller and hence less ventilation. Also the is put in parts of the house where there is no scope of cross ventilation. Fanger(22) sums up "After a heavy meal rich in protein, influence could be greater, probably decreasing the optimal temp. up to 1°C for some hour."*

2.4.0. THERMAL INDICES

It has been described before that comfort depends on various factors. So the designer faced the problems of handling independent variables simultaneously. Many experiments have been done to devise a single scale which combines the effect of all these

* Fanger, P.O. "Thermal Comfort".
Denish Technical Press 1970 P.92.

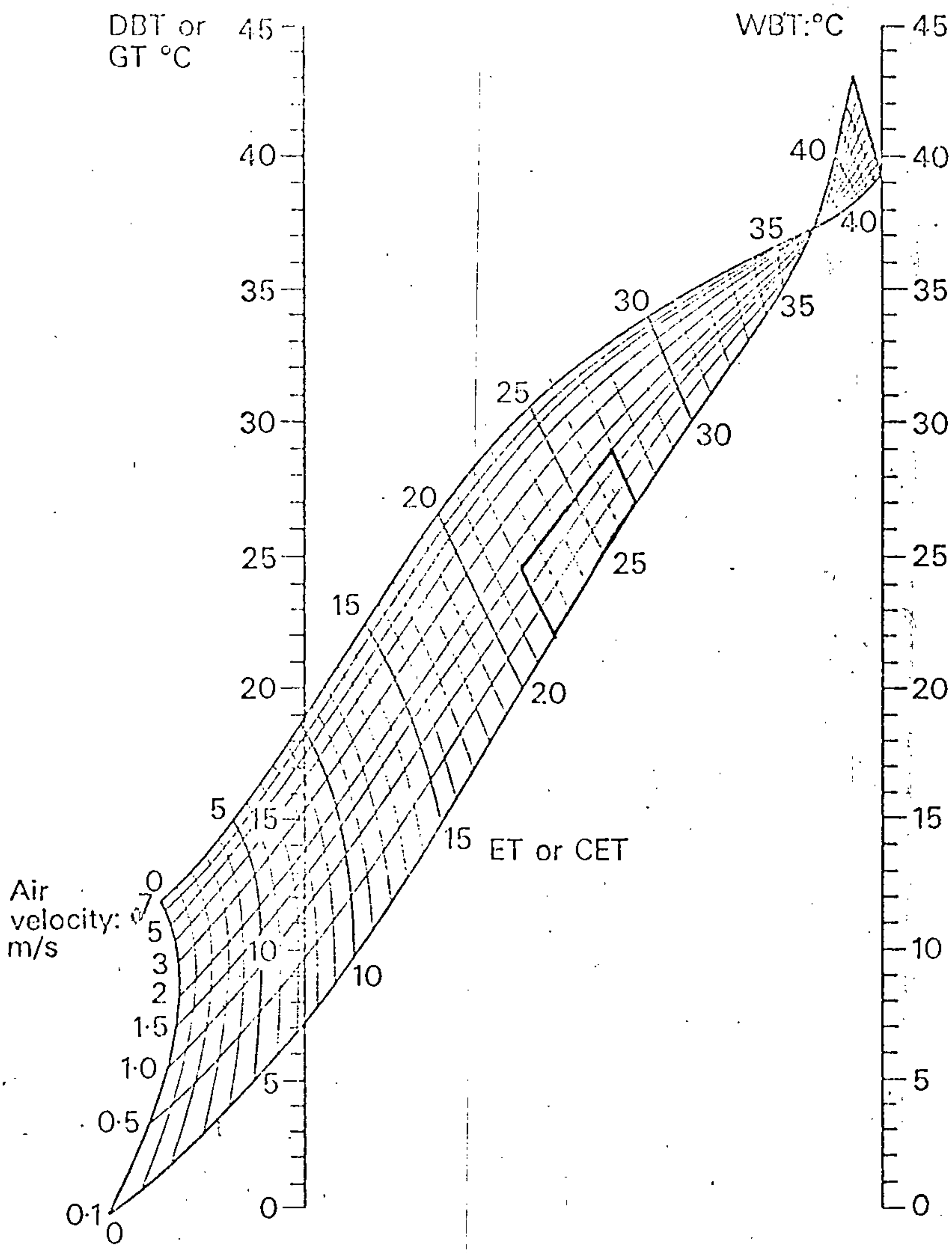


Fig. 7a. Effective temperature nomogram for persons wearing normal business clothing (1 clo).

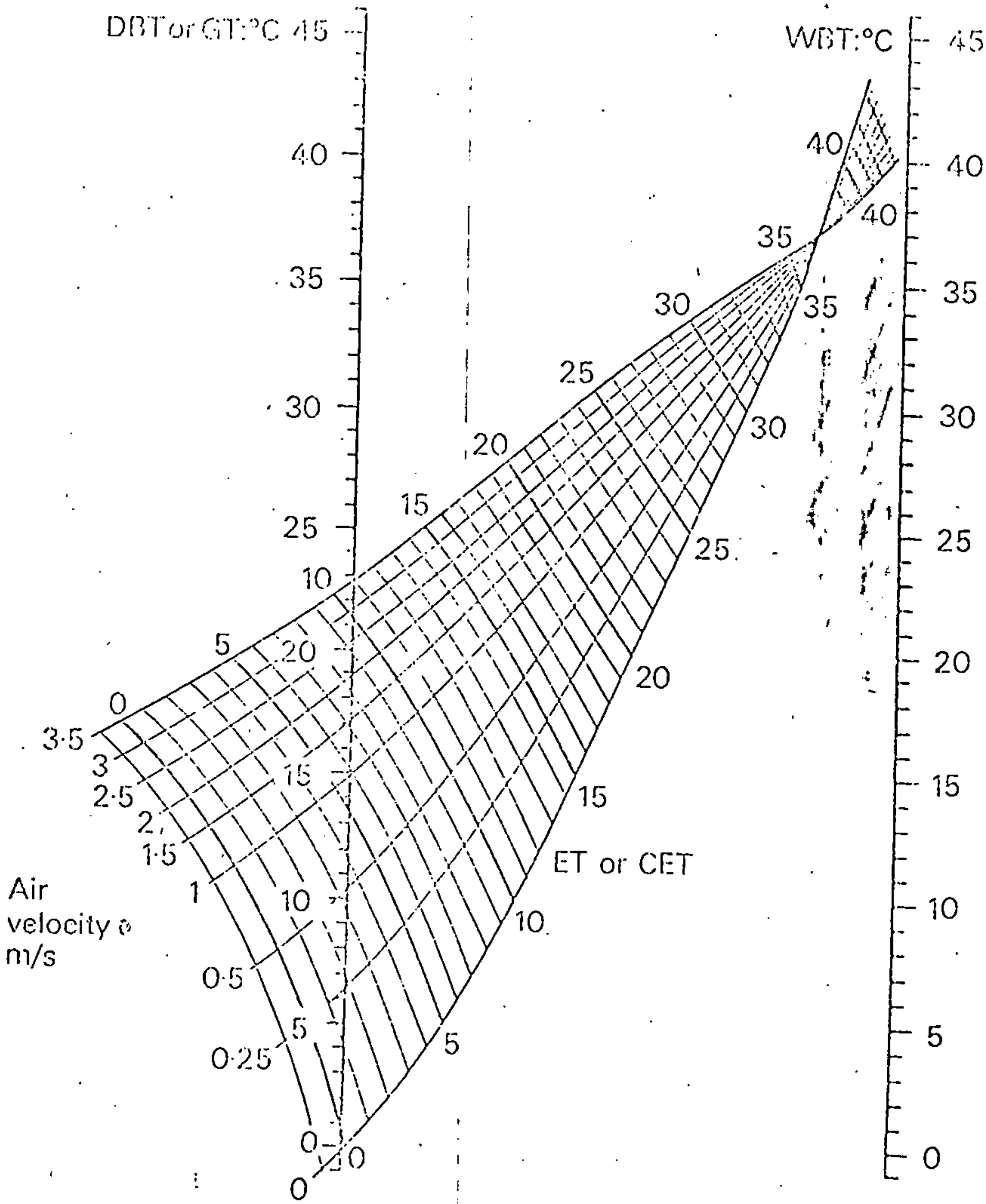


Fig. 7b. Basic effective temperature nomogram for persons stripped to the waist.

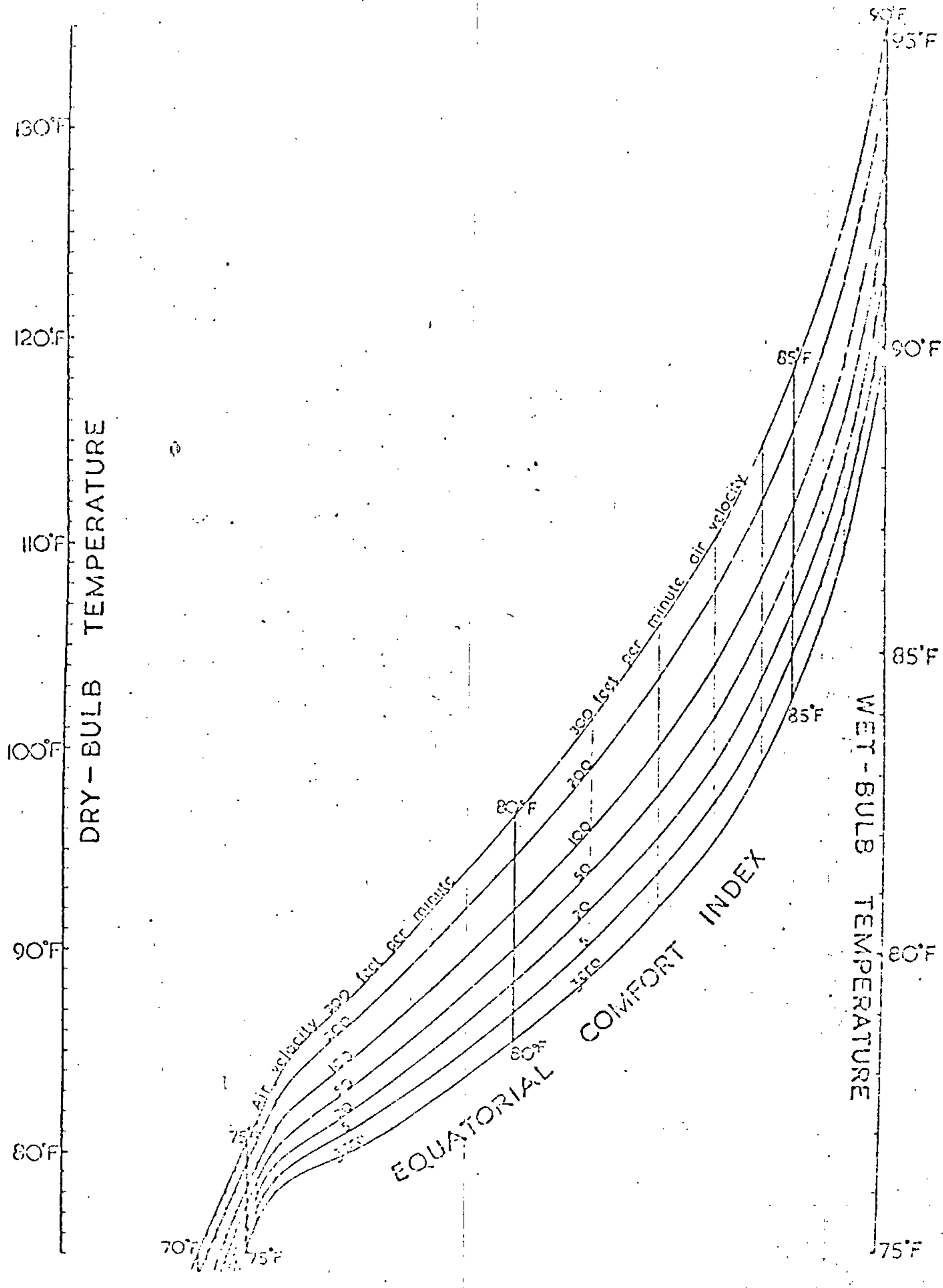


Fig. 7c. Nomogram for the Equitorial Comfort Index.

factors. In doing so various researchers came up with different scales. All these scales are collectively called Thermal Indices. Thermal indices like Effictive Temperature (E.T.), Corrected Effictive Temperature (C.E.T.), Equitorial Comfort Index (E.C.I.), Resultant Temperature (R.T.), Predicted Four Hour Sweat Rate (P_4SR), Heat Stress Index (H.S.I.) and Index Of Thermal Stress (I.T.S.) have been described in the appendix3. Of these E.T. or C.E.T. is mostly used and understood. E.T. and E.C.I. charts are shown in fig.7a, 7b, & 7c.

2.4.1. Some of the experimental results of studies on comfort zone, expressed in E.T. as given by Lippsmeier(17) are shown below.

Invistigator	Locality	Group of people	Comfort zone
A.S.H.R.A.E.	Southern U.S.A. 30° North	Research worker	69 to70°deg.F
Rao	Calcutta 22° North	Indian	68 to 76
Webb	Singapore Equitorial	Malays, Chinese	77 to 81
Mom	Batavia ° South	Indonesian	68 to 79
Ellis	Singapore Equitorial	Europian	72 to 79

This is interesting to note that Webb and Ellis arrived at slightly different results under similar conditions. This should not be attributed to difference of subjects as Asian and Europian. In this connection I would like to quote Fanger's comment.

"- - comfort study by Ellis among 152 Europian and Asian residents in Singapore. An optimal temp. of 27°C was found at r.h. 80

percent and a mean relative velocity of 0·4 m/s for persons with typical tropical clothing which can be estimated to have a clo value equal to 0·4. - - - - - - Ellis found no difference between the Europians and Asians. In another field study in Singapore, including only 14 subjects Webb found ander approximately the same condition as Ellis, an optimal temperature of 28·5° C. "*

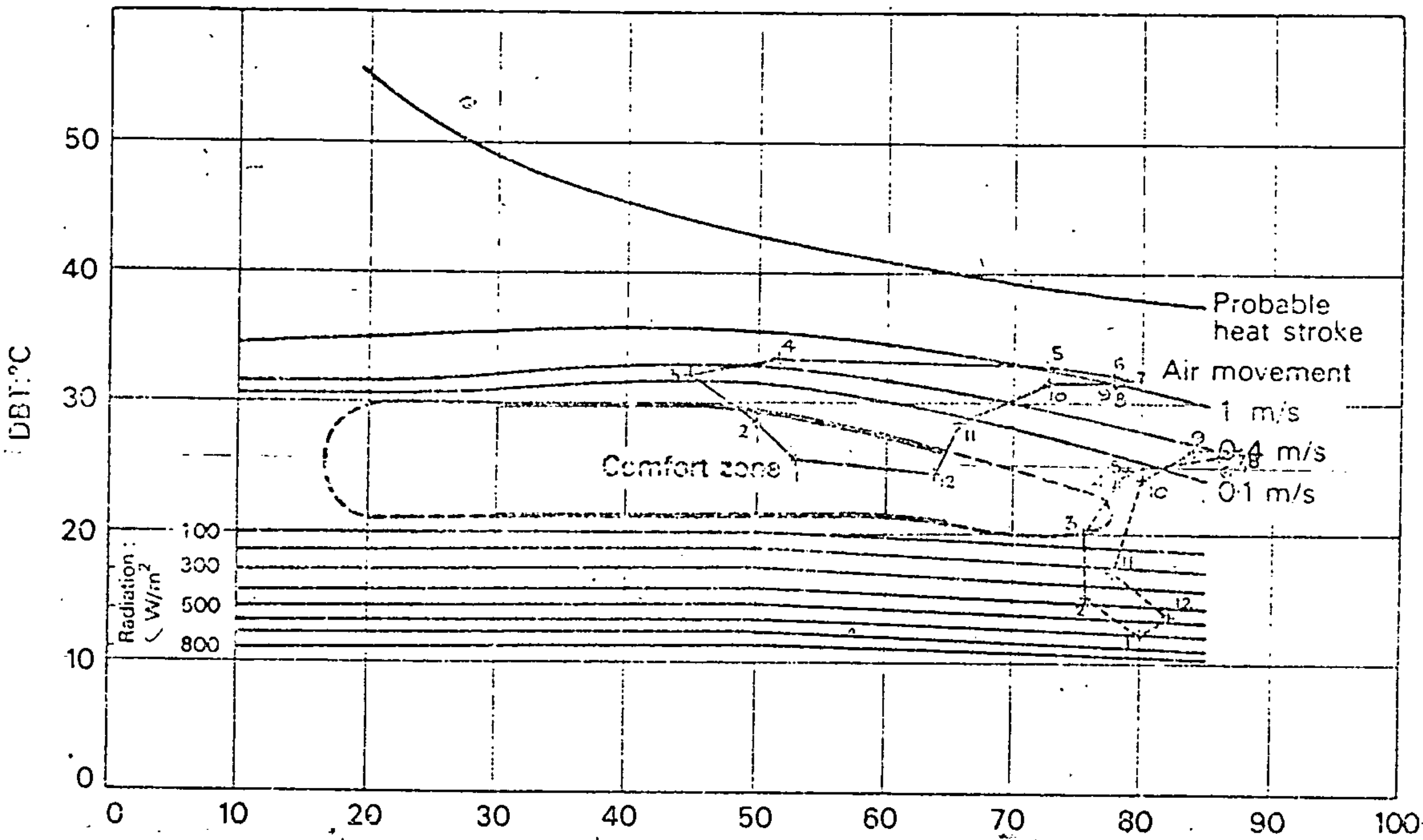
2.4.2. Bioclimatic chart: It is observed that D.B.T. values correlate much better with subjective judgement than E.T. values. V.Olgyay(24) argues that there is no point in going for complicated calculations in constructing a single figure index, as all the variables are controlable by different means. He developed the bioclimatic chart where the comfort zones are defined in terms of D.B.T. and relative humidity. He also charts the effects of air velocity and radiation. The former pushes the comfort zone upwards and the latter draws it downwards.

2.4.3. Climatic data of Bangladesh have been plotted on the chart to show the periods of comfort and discomfort and the degree of devitation from the comfort condition. Six set of values have been plotted.

A. Set of data indicating day time situation based on mean monthly value.

B. Set of data indicating night time situation based on mean monthly values.

* Ibid P.83.

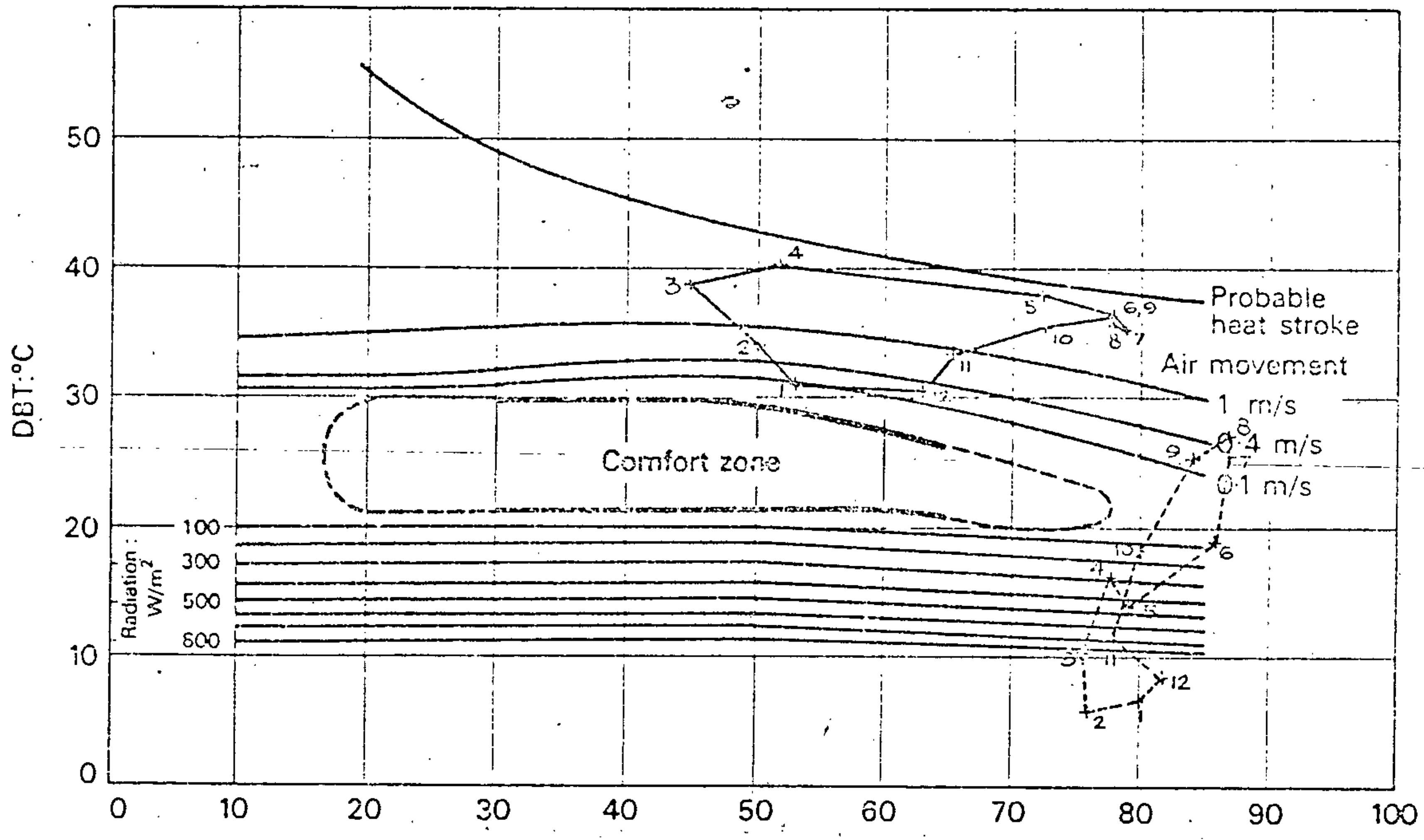


RH: %   Numbers in the graph indicate month of the Year

9 a.m. humidity (high) & low temperature, assumed night condition ———

6 p.m. humidity (LOW) & high temperature, assumed day condition - - - - -

FIG. 8

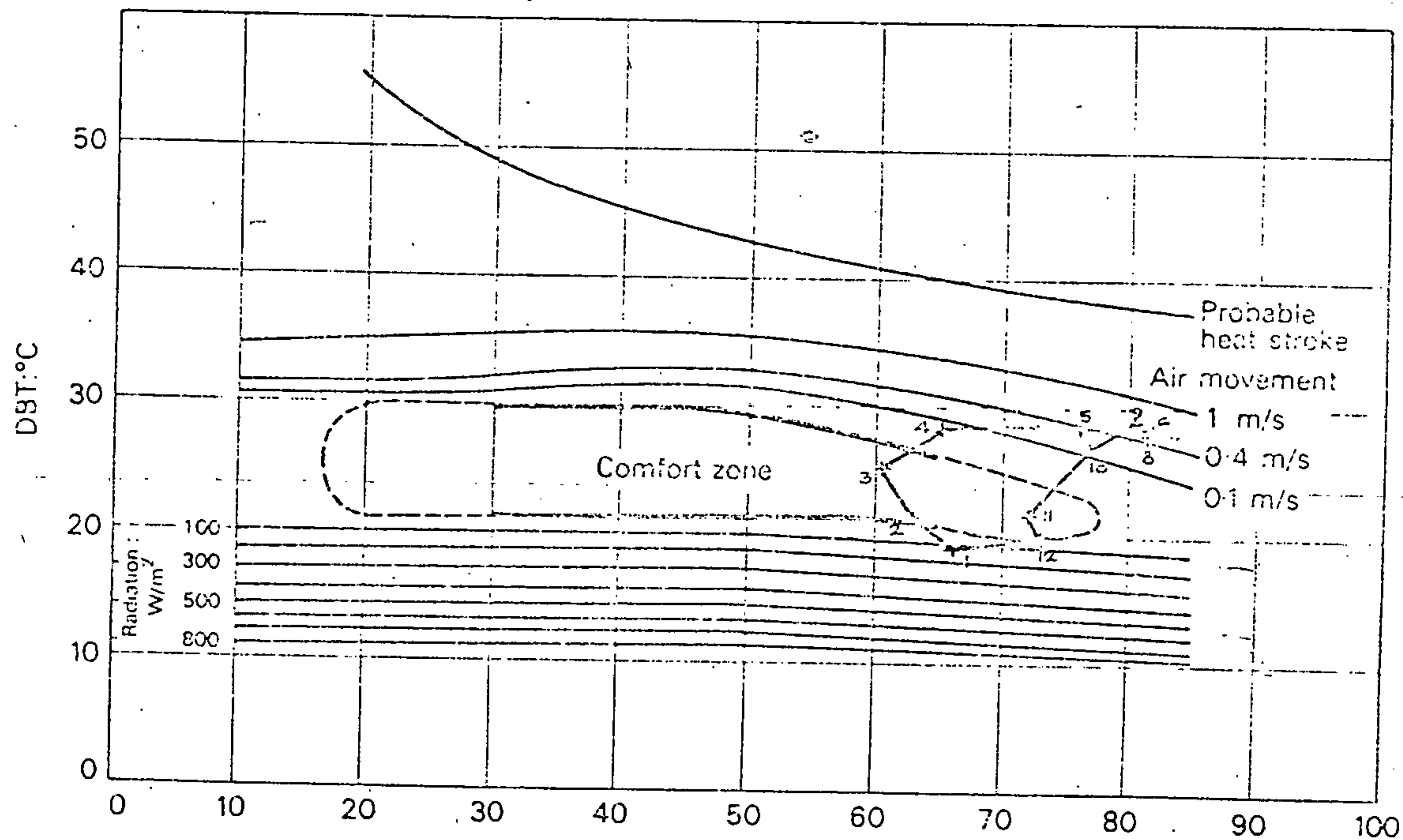


Numbers in the graph indicate month of the year

extreme conditions considering absolute max. temperature day ————

extreme conditions considering absolute min. temperature night --------

FIG. 9



Numbers in the graph indicate month of the year
Points are plotted with average values of temp. & r.h.

FIG.10

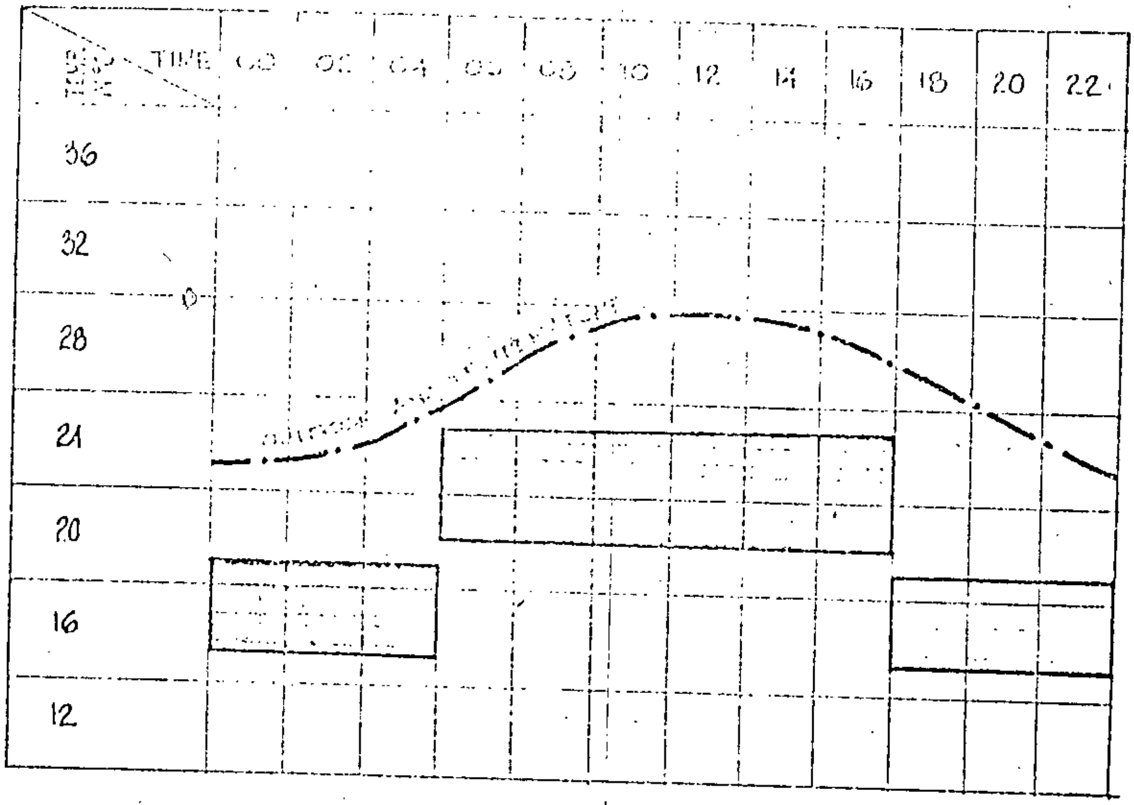


Fig. 11. the temp. and comfort curve for a typical summer day in the month of June.

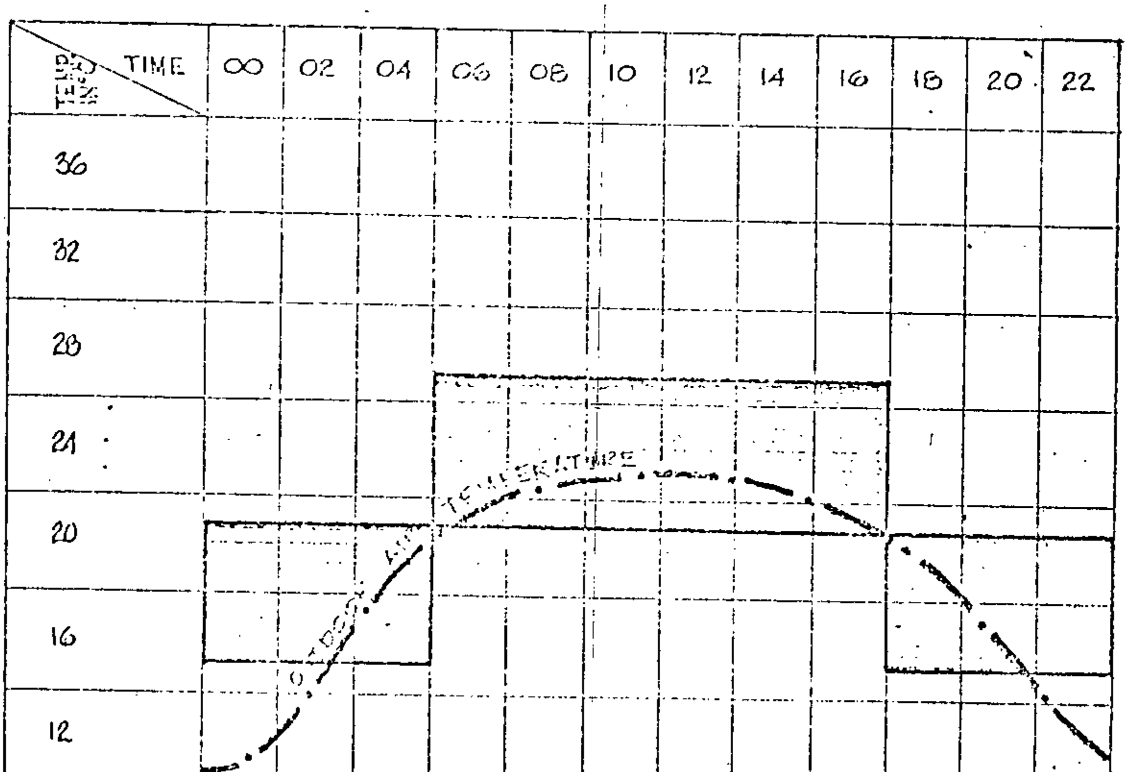


Fig.11. the temp. and comfort curve for a typical winter day of January.

C.a. Set of data indicating day and night situations based on monthly absolute max. and min.

E.d. Set of data indicating day and night situation based on average monthly data.

Detailed hourly data was not available. So suitable combinations were chosen for interpolation.

Fig.8,9,10 show the plotted charts.

2.4.4. Mahoney table: Depending on subjective judgement Mahoney developed a table indicating comfort limits. He took into consideration air temp. temperature range and relative humidity.

Climatic data of Bangladesh were tried and the results were plotted as shown in the fig.11. The tables are given in appendix3. For this table ditailed data was not necessary. The graph roughly shows the limits of comfort; the periods within the comfort zones, and the deviations from the limits of comfort.

2.4.5. Conclusions: From these two charts a reasonably clear picture can be obtained about the climatic situation of Bangladesh in relation to comfort conditions. Following conclusions may easily be made.

a. During summer months from April to October the prevailing conditions are well above the comfort zones. Considering the absolute values the situation is worse. So a continuous movement of air between 1 and 2 m/s is necessary to attain reasonable comfort level. That is the velocity of air in the interior at body level should be maximised.

Effect of radiation should be minimised. That is the windows and walls should be shaded.

B. From the chart it is observed that day times of December, January and February are within the comfort zone and are quite pleasant. Nights are cold and below the comfort zone. March and November are also quite close to the comfort zone. Nights are pleasant and days are a bit warm but not very unpleasant.

So for three winter months no comfort ventilation is necessary. Infiltration of cold wind should be restricted specially at night. During this time sun rays may be allowed to enter the interior spaces and insolation of the walls should be maximised. In March and November some air flow during day time will bring in comfort condition.

CHAPTER THREE CHAPTER THREE

3.1.0. VENTILATION REQUIREMENTS:

Ventilation is required for three reasons. These are;

A. Health ventilation: To maintain the quality of the air inside the building above a certain minimum level by replacing indoor air, that have been vitiated by the process of living and occupancy, by fresh indoor air. This is often termed as health ventilation. This is an absolute necessity independent of climate.

B. Structural cooling ventilation: To cool the structure when its temperature is more than the outside temperature. This is often termed as structural cooling ventilation.

C. Comfort ventilation: To provide thermal comfort by increasing heat loss from the body through evaporation of water from the body. This is often termed as comfort ventilation. (15)

A design of ventilation should satisfy all these three requirements. The magnitude of the requirements of these three conditions depend on the local climatic conditions.

3.2.0. HEALTH VENTILATION:

Apparently this do not seem to be very important for Bangladesh. But this becomes important where flue less cooking device is used, specially when the fuel is fire wood. The ventilation rate should suffice to keep the carbon and other products of combustion below the level hazardous to health.

3.2.1. The outdoor air contains on the avarage about 21 percent oxygen, 0·03 - 0·04 percent carbon dioxide, 78 percent nitrogen, 1 percent inert gases (argon) and between 5 and 25 percent grams of vapour per cubic metre of air. Expired air contains about 16·3 percent oxygen, 4 percent carbon dioxide, 79·7 percent nitrogen and other gases discharged by the body (mainly ammonia) and about 45 gm/m^3 water vapour (saturated air at 37°C). In occupied buildings air quality is substantially affected by metabolic activity and living process of the occupants. Carbon dioxide and water vapour are discharged from the lungs. Bacteria are discharged with breathing, sneezing and caughing. Odour producing organic materials are given off by the body, to some extent dependent on personal hygine and diet; smoking pollutes the air from both health and odour aspect. (15)

3.2.2. Air becomes harmful when oxygen content falls below 16 - 18 percent and carbon dioxide content rises to 1 - 2 percent. This is of very little significance in structures like housing and school buildings. So carbon dioxide and oxygen content can hardly be used as direct criteria for the specification of ventilation requirements. But carbon dioxide content gives an indirect indication of pollution of indoors. Other elements that affect the quality of air is not so easily quantifiable as carbon dioxide. Givoni (15) suggests a level of 0·2 percent carbon dioxide as criteria for specifying minimum ventilation in residential office and school buildings. A calculatin of requirements of ventilation on this basis is given in appendix 3.

3.2.3. ODOUR:

The stimulus of odour that is the subjective perception of of odour is extrimely sensitive. It is more sensitive than instrumental detection. Fortunately adaptation to odour occurs rapidly. A person entering a space may find the odour very disturbing but after a few minutes of adaptation quite a high level of odour can be tolerated.

3.2.4. Body odour dissipates quite readily even without air change. It is much less stable than odour from chemical materials. As in the case of cigarette smoke the intensity is increased during the first three hours and is decreased very slowly after that. Consolazio and Pecoria studied the effects of ventilation on odour level according to following scale.*

No odour	0
Threshold odour barely perciptible	1
Definite odour, but not objectionable	2
Strong objectionable odour	3
Very strong disagreeable odour, yet tolarable	4
Overpowering, unbearable and nauseating odour	5

Subjective odour impressions were of two types: instantaneous— immidiate after entering. Residual— after one minute of exposer. The first impression is usually higher than the residual by about 1·2 points in the subjective scale. The reduction of air temp. from 87 to 71° F were equivalant to increased ventilation of 5 to 53 cft. per min. per person indicating increase in odour offensiveness with increase in temperature.

*Consolazio, W.V. and Pecora, L.J. "Minimal Replenishment Air Required For Living Spaces" SHAVE Jour. section, APAC, March 1974 P 103 - 114.

3.2.5. Health ventilation is important in tropical countries in spaces like kitchen, bath, etc. specially when there is no external window. It is preferable for these spaces to have at least one exterior wall with opening above eye level, when there is no forced ventilation. Givoni (15) suggests a minimum of 6 complete air changes per hour for toilets.

3.2.6. CARBON MONOXIDE:

Carbonxide is produced due to incomplete combustion. It is toxic even at a very low concentration of 0·3 percent. In a country like Bangladesh where possible carbonmonoxide concentration is at the kitchen only, pose no problem. The required air change will take place through the cracks in case all the windows were closed.

3.3.0.0 STRUCTURAL COOLING

In Bangladesh situation it may be assumed that buildings with white external colour, medium to high thermal resistance and low heat capacity and properly shaded windows have a daytime indoor temperature same as outdoor temp in shade. Dark coloured buildings ~~buings~~ having poorly shaded windows have daytime indoor temperature above the outdoor temp. At night the outdoor temperature is almost always lower than the indoor temp. In an well ventilated building difference of indoor and outdoor temp. is small. So in hot humid situation proper ventilation is necessary during day and night except for short winter months.

3.4.0. COMFORT VENTILATION

Health ventilation is independent of climatic condition but comfort ventilation is very much dependent on climatic conditions of the locality. It is a function of the temperature and vapour within the building.

3.4.1 Comfort ventilation has to consider almost all the physical, physiological and sensory aspects of the body in relation to its environment. Physical aspects are metabolic heat production, convection and radiation heat exchange, and evaporative heat loss. Physiological aspects are circulatory regulation, that is increase or decrease of blood flow, sweating that is passive water from the lungs and skin and active sweating by secretion of sweat glands, inner body and skin temperature etc. Sensory aspects include subjective responses like thermal sensation and sensible perspiration (skin wetness).

3.4.2 Evaporative cooling required (E) is the resultant of the metabolic heat production, convection and radiation heat exchange. For comfort condition E/E max is suggested to be 0.1. There is reasonable increase in comfort with the increase of velocity of air upto a temperature of 35°C (95°F). Above this, the convective heat gain and evaporative heat loss act in the opposite direction, and after that, any more increase in velocity is of no significance.

3.4.3. Ventilation is not the only determining factor; metabolic heat rate, humidity and clothing conditions are also significant factors. However, in hot humid situation like Bangladesh, increase in ventilation is almost always associated with improvrd subjective comfort.

3.4.0. MECHANISM OF VENTILATION

Air movement through a building takes place due to the pressure gradient accross it. The pressure gradient is caused by two sources.

A. External air velocity or wind force.

B. Temperature gradient between indoor and outdoor air.

3.4.1. Thermal force generates because of density difference between indoor and outdoor air caused by temperature. This is also influenced by the difference of heights of the two openings provided. This is known as stack effect. The formula for determination of the force is given in the appendix 3.

3.4.2. Van Straaten et al say that the contribution of thermal forces to ventilation is quite small, specially during day time when the temperature difference between indoor and outdoor air is small.(27) But Webb argues that thermal force is of considerable importance in Malaysia (climate is very similar to Bangladesh). It is important because of two reasons;

A. Outdoor air is still for a considerable time of the year during day and night.

B. Because number of persons living in a room is high and hence the metabolic heat produced is very high.

His heat and moisture balance equation is given in appendix 3.

3.4.3. When wind is blowing on to a building a pressure difference is set up accross the building. The pressure is higher than atmospheric on the wind ward side known as pressure zone. The pressure is reduced on the lee ward side known as suction zone. An equation expressing air flow through openings is given in appendix 3.

The effectiveness of a particular wind to flow through a building depends upon the speed of the wind, the direction from which it comes and the frequency with which it blows.

CHAPTER FOUR CHAPTER FOUR

4.1.0. It has been stated before that in hot humid climate as the case in Bangladesh air movement is the most significant single feature to provide maximum possible comfort. To assure maximum air velocity inside the rooms at the body level is the objective to be attained. But maximum velocity is attained in case of laminar flow, mainly because it does not allow enough time for the air to mix with the air inside the room and it does not allow air to reach all the corners of the room. Thus the aim is to induce turbulent flow inside the room. The airflow should be so designed that it provides maximum cooling effciency by evaporative cooling. The air movements depend on the following factors.

A. Location of buildings relative to one another.

B. Orientation of the building.

C. Cross ventilation through the interior.

D. Position of openings, both inlet and outlet.

E. Size of openings, both inlet and outlet.

F. Control of opening.

4.2.0. FACTORS AFFECTING AIR MOVEMENT

4.2.1. Location of buildings: The air flow inside the building depends on the outside air velocity. Hence the air flow around the building is significant. A building hardly stands by itself. The location of structures or trees in the proximity of the building influence the flow around the building which in turn govern the indoor air movement. Proper location of tall blocks

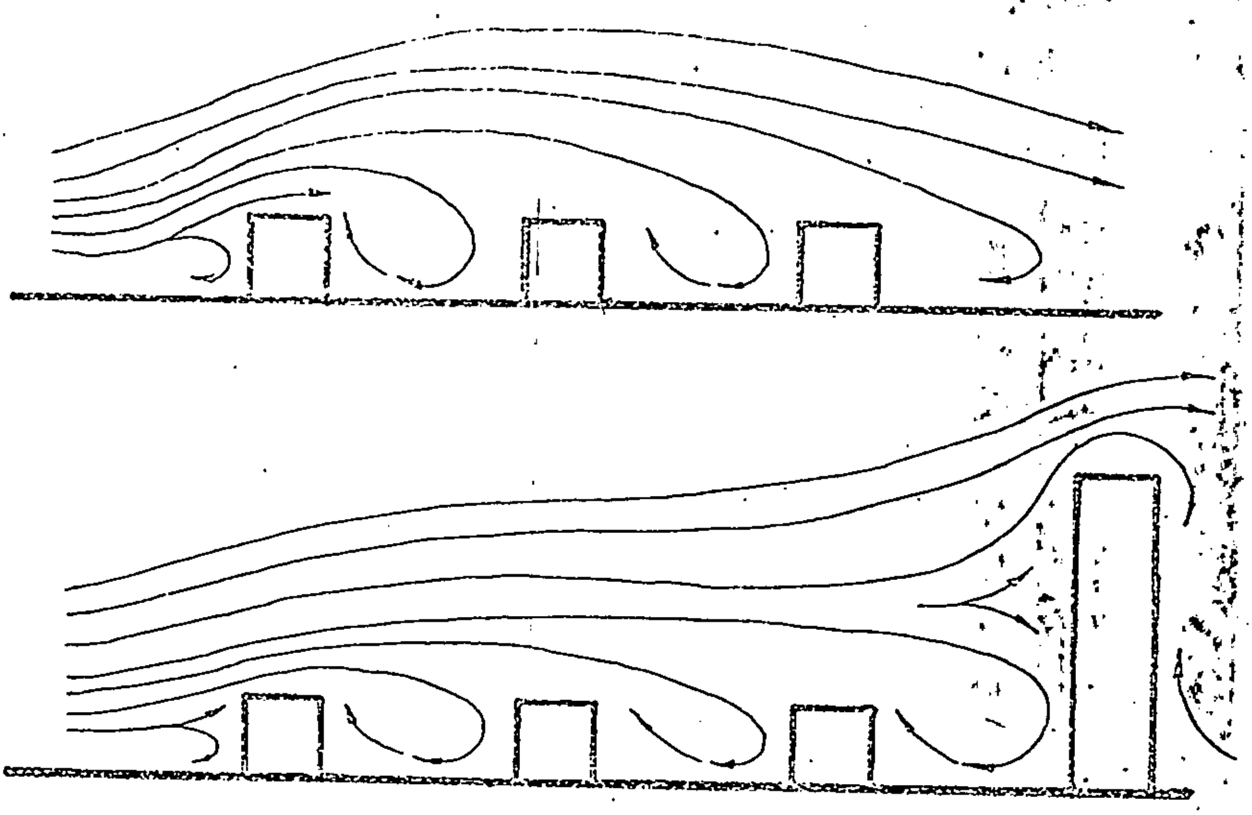
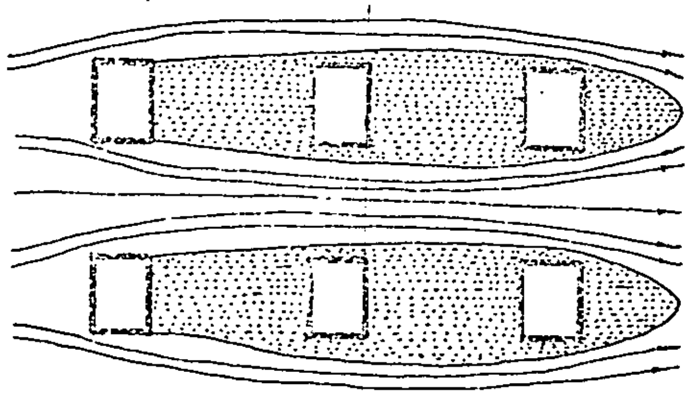


Fig. 12. Suitably placed high building may help the air flow.



Air flow in a gridiron layout, long wind shadow is formed

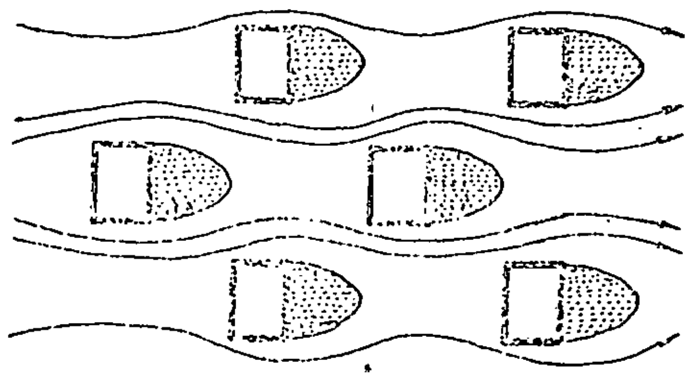


Fig.12a. Air flow in a checker-board layout

can help the air flow around the low rise buildings as shown in the fig.12.

Based on experiments at the Architectural Association Department of Tropical Studies, Koenisberger says that "If in a natural setting in open country, single buildings are placed in a grid-iron pattern, stagnant air zones leward from the first row will overlap the second row. A spacing of six times the building height is necessary to ensure adequate air movement for the second row."* He also says that in a similar setting if the buildings were staggered in a checker board pattern the flow would be much more uniform. The two conditions are shown in fig. 12 a .

In a recent study done at the University of Edinburgh, Muktadir says that "It is clear that adequate wind velocities at the inlets for summer ventilation requirements can be achieved at a relatively short spacing of 3H ".** Depending on the direction of wind, spacing and pattern of layout an innumerable variety of situations may be arrived at. Prediction of inlet velocities in such cases is only possible after a model study in wind tunnels. There is scope of further studies in the field. However

*Koenisberger, et al "Manual of Tropical Housing and Building" Longman, 1974 P.122-129.

**Muktadir, M.A. "Climatic Aspects of High Density Urban Housing in Warm Humid Tropics" Ph.D. Thesis, Univ. of Edinburgh. P.127

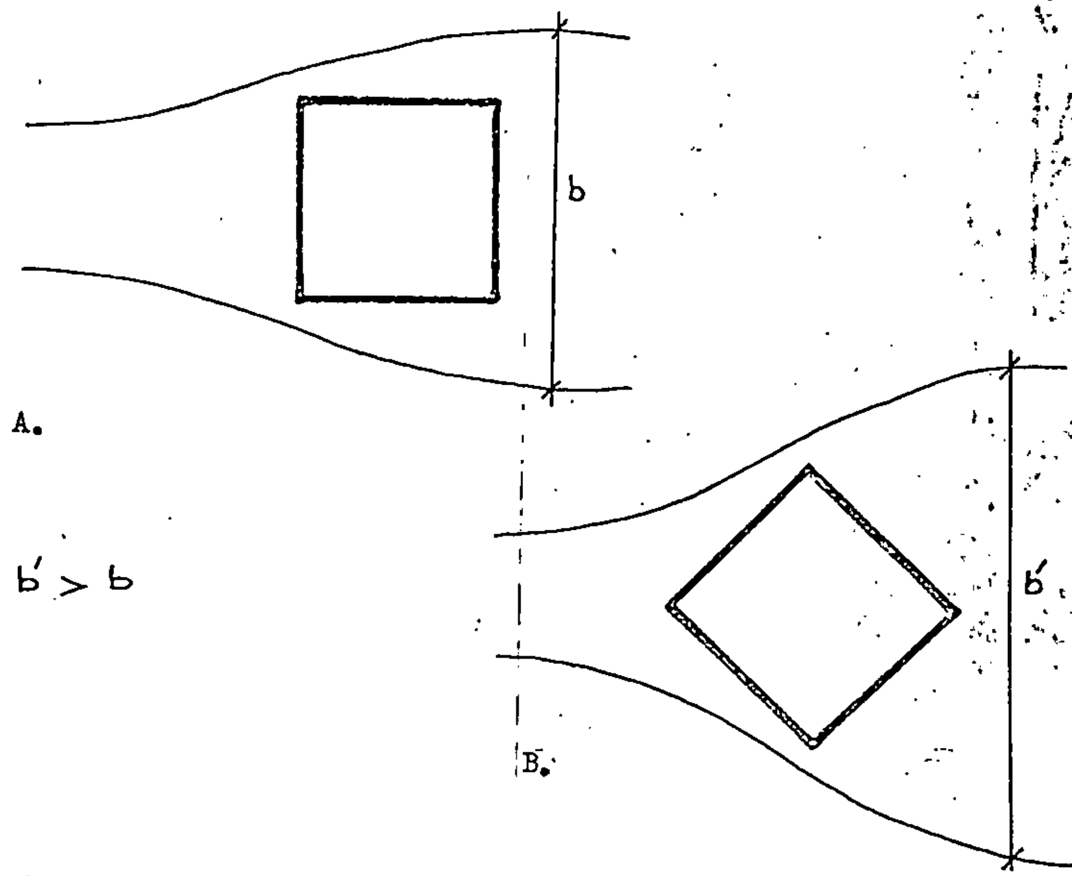


Fig.13. In case 'B' broader wind shadow
and increased negative pressure zone will produce better air flow.

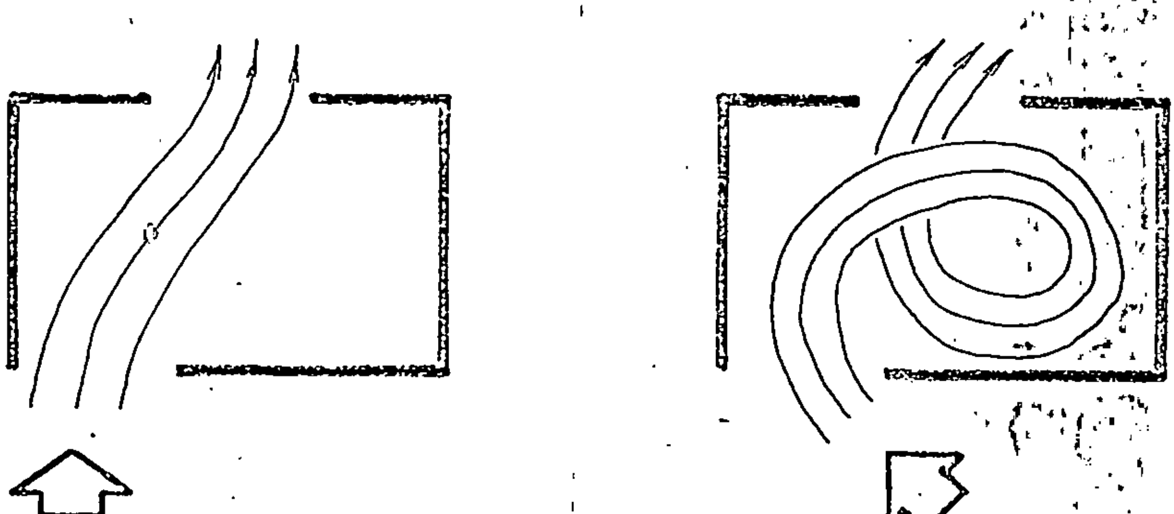


Fig.13a. Oblique wind moving most of the air volume

all seem to agree that a gridiron layout with oblique wind direction and a checker board layout with perpendicular wind direction show better performance regarding air flow around buildings.

Vegitation planted by the side of the building has substantial effect on wind velocity at the inlet. Hedges has a much more pronounced screening effect on the building than trees. (27) The reason for this is that trees with bare trunk of about 5 to 6 ft. above the ground allows flow to take place underneath them. It is not possible in the case of a solid obstruction from the ground level as in the case of a hedge. The effect of trees planted some distance apart from each other, is less than when trees are planted in a solid row. To facilitate ventilation trees may not be planted too close to the building and too close to each other. (fig.14)

4.2.2. Orientation: Apparently it seems that maximum air flow will be be obtained when the inlet window face the wind directly. But Givoni (15) shows that it is not so. The outlines of air flow in the cases when wind hits perpendicularly and when wind hits at an angle is shown in the fig.15. In the case 'B' greater velocity is created along the windward faces and the wind shadow is greater. The larger negative pressure on the leward side will create greater indoor air flow.

When the two windows face the opposite walls, and the external wind direction is perpendicular to the inlet, the main air stream flows straight from inlet to the outlet causing very little air movement in the rest of the room, particularly the corners of the inlet wall. But when the wind is oblique to the inlet a turbulence is created moving most of the air volume, increasing the air flow along the side walls and the corners. Fig. 13a explains the phenomenon.

When the two windows are at the adjacent walls the oblique wind takes the straight path. So better wind flow is obtained when the external wind is perpendicular to the inlet. Fig. 14 explains the phenomenon.

The observations are significant because it gives the designer some free play in the location of windows. He can take advantage of maximum benefits of orientation in relation to solar radiation, and also manipulate the wind flow by various location of windows for optimum ventilation.

4.2.3. EXTERNAL FEATURES:

External features of the building can strongly influence both the indoor air flow and the initial velocity at the inlet. External features need careful consideration regarding solar control, rain protection and air flow.

Any staggering of the facade, 'L' shaped layout and projected wings or ends may put the inlet windows in wind shadows as

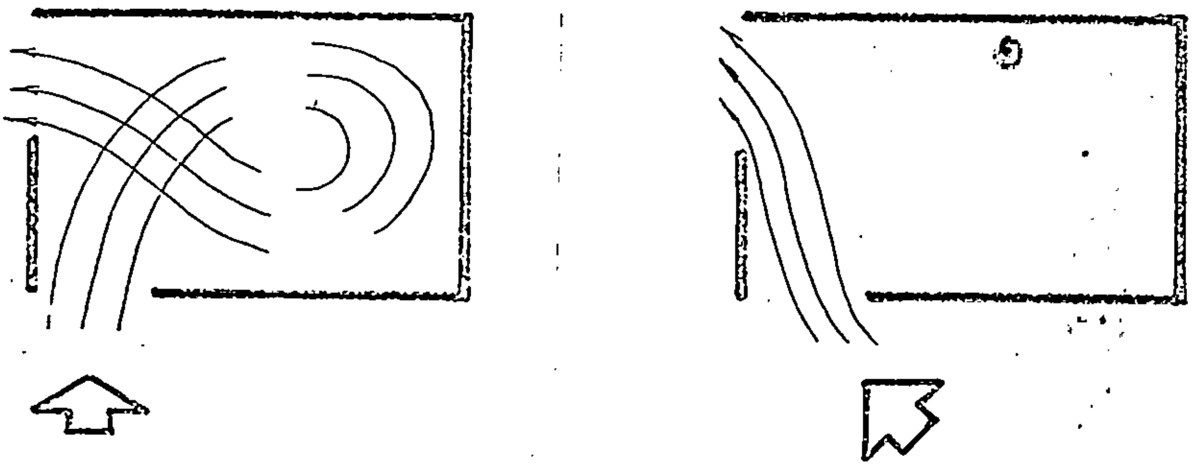


Fig. 14. Windows are on adjacent walls,
wind perpendicular to the inlet producing better air flow

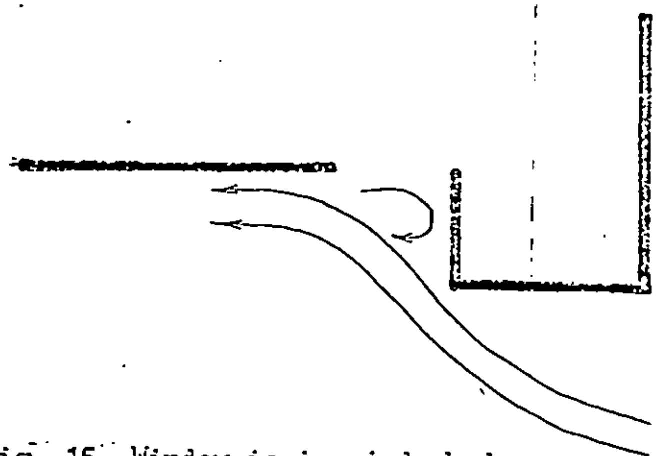


Fig. 15. Window is in wind shadow
due to projected end.

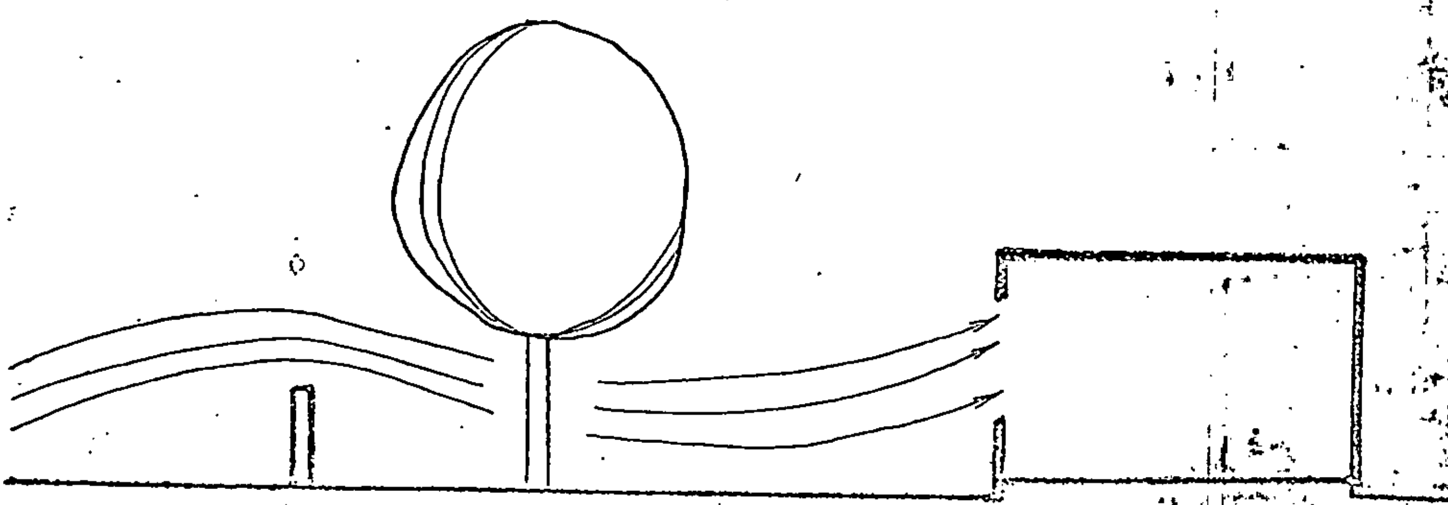


Fig.16. Boundary wall and tree properly guiding air flow

shown in Fig.15. Putting windows in the wind shadow will be useless. So from ventilation point of view in Bangladesh, the south side of the building should be without staggering as much as practicable. If the west end is extended forward, it might be helpful when the summer wind blows from the south-east direction.

Fly screens are necessary in hot humid climate like Bangladesh. But fly screen effect the wind velocity substantially. Van Straaten(27) found that a 16 mesh 30 gauge wire screen may decrease the total flow by about 50 percent when the wind velocity is 2 m.p.h. The decrease become lesser as the velocity increases. Oblique wind seem to slip over the screen besides reduction in velocity. That is the adverse affect of screen on ventilation is intensified when the wind is oblique. It seems to be a better idea to put the fly screen over the balcony than on individual windows. In that case wind has a larger area to penetrate through. But weathering effect reduces the life of the screen.

Boundary walls are very common features in Bangladesh housing areas for reasons of security, privacy, noise and dust control. Their height and proximity may drastically reduce the flow of air. For dust control purposes, it is better for the wall to be high --- 5 to 6 ft. --- and close to the building. For air flow the reverse is true. Boundary walls in association of trees may sometimes be gainfully used to direct the flow of air as shown in the Fig.16. The figure also shows the careful use of hedges and low walls.

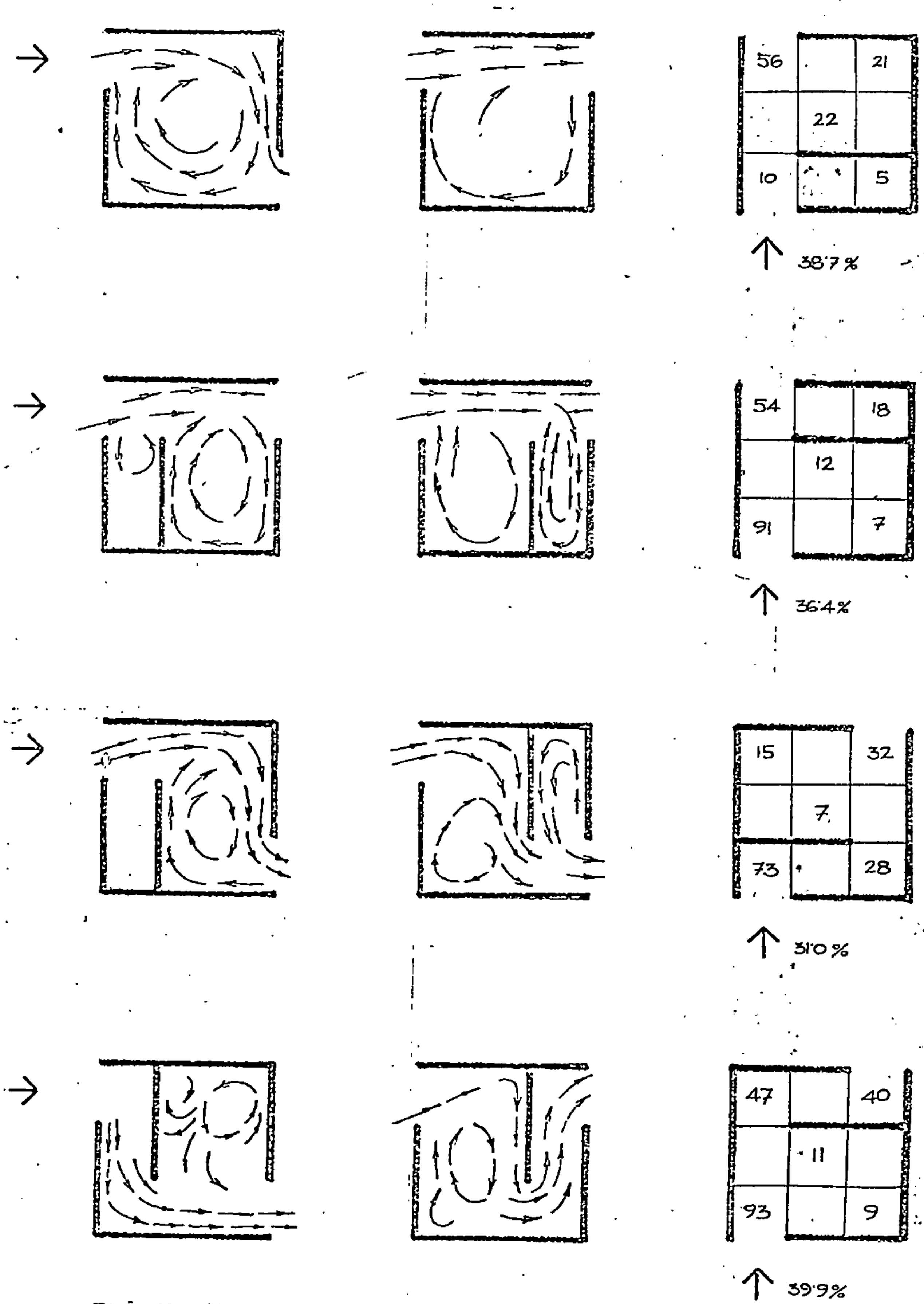


Fig. 17. Air movement and distribution affected by partition wall. Preferable for the upwind room to be larger.

4.2.4 CROSS VENTILATION:

When the wind ward pressure zone connected by appertures through a space to the leeward suction zone, it is known as cross ventilation. A space having windows on any two walls regardless of their position in relation to wind direction do not give rise to cross ventilation. With openings on the windward side only without any outlet, pressure similiar to the front of the building, may develop indoors. Such condition increases discomfort. The aim of cross ventilation is to obtain and control proper air flow through the interior.

Any obstructions within the space, with windward and leeward windows, greatly influence cross ventilation. Partition walls, obstructions, non-rectangular planning of rooms, etc. do not only change the direction of the air stream, but also drastically reduce it. Thus narrow one room deep slab like buildings have better cross ventilation than compact cube shaped ones.

Partition walls should be completely perforated or have air openings even if the doors in them are kept permanently open. Some air movement situation in rooms with partition walls are shown in the Fig.17. It is preferable for the upwind room to be larger. However, partition walls disturb the air flow and give rise to large still areas. Fig.17 further explains the distribution of air in a room having partition wall with opening in them.

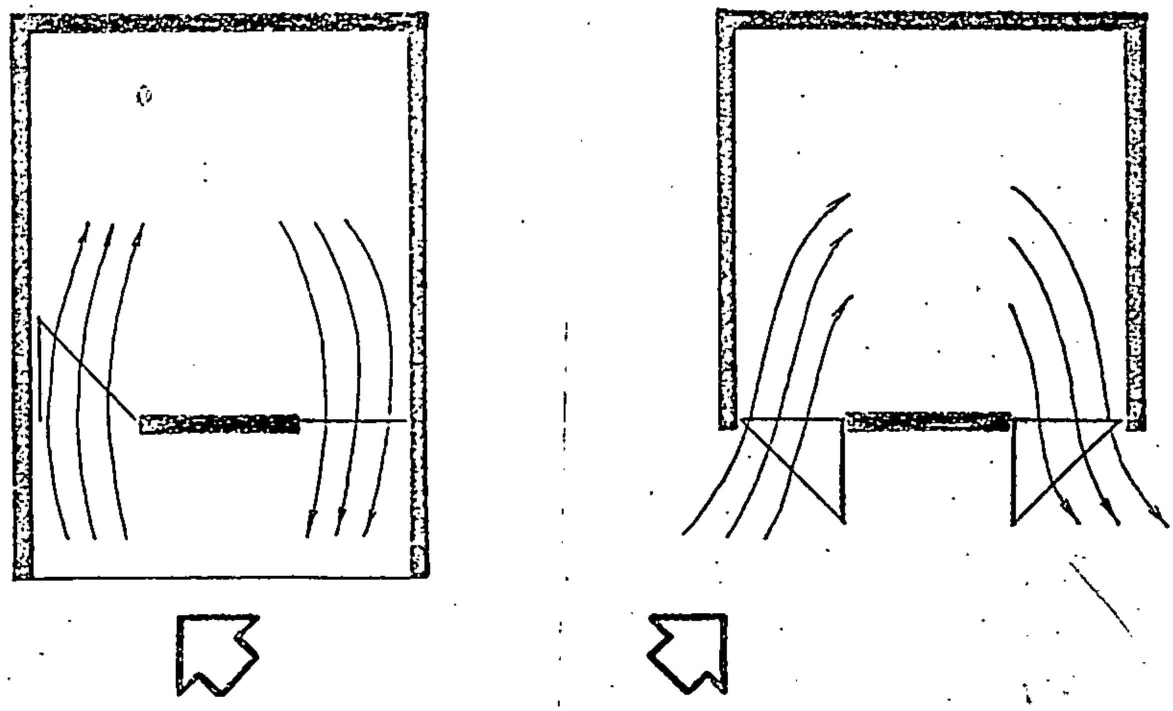


Fig. 18. Balcony gainfully utilised to aid air flow.
Single leaf casement window opening outside serving the same purpose.

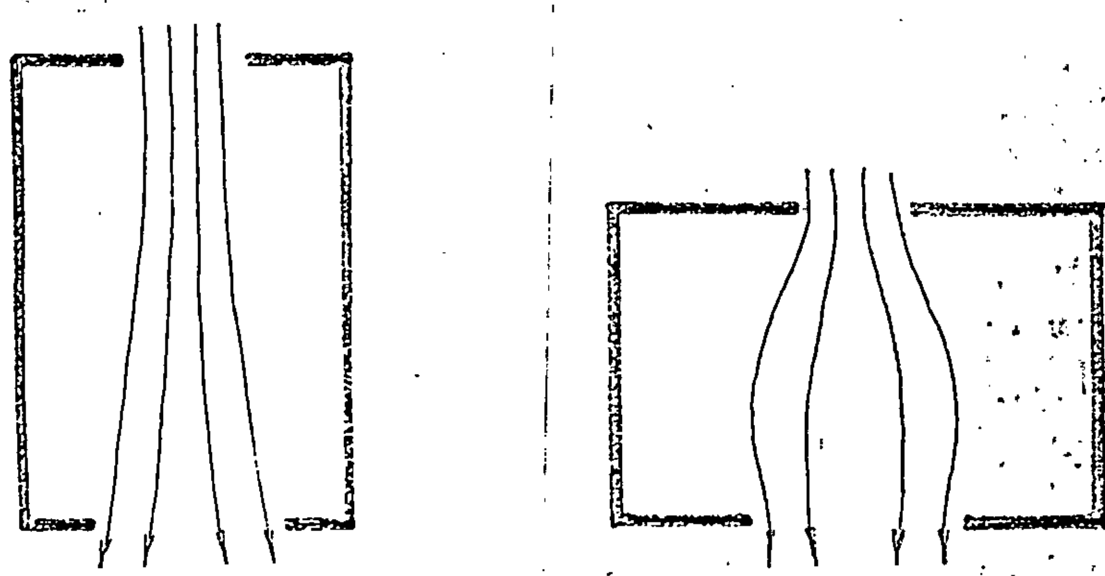


Fig. 19. Windows put in narrow walls produce better results than windows put in wider walls.

In general room with windows on one side only are poorly ventilated. However some improvements may be made by the adjustment of the details of apperture design. When wind is oblique in relation to the window, there is a flow of air along and parallel to the length of the wall. This creates a small pressure gradient in its path inducing a flow from the high to the low pressure sections. If two lateral windows are provided at the up wind and down wind sides of the room, the ventilation condition is improved. Pressure difference and hence the ventilation may be further improved providing each of the two windows with a single vertical projection.

Balconies may also be designed in conjuction with the openings taking advantage of the side wall of the balconies. Single leaf casement windows opening outside may also create same effect. (fig.18) The improved ventilation effect due to the projection will be lost if it is put on both sides of the window. This may be noted that ordinarily for a room with single exterior wall with windows the indoor velocity is not more than 20 percent of the exterior. All the improvements suggested may double the amount, that is the indoor velocity may be a maximum of 40 percent of the outdoor. In hot humid climate this level of ventilation is not satisfactory.

4.2.5. POSITION OF OPENING:

In positioning an opening there are three main points to be considered. The vertical location, horizontal location and the wall in which opening is to be provided. It may also be considered, if permanent openings are to be provided. By proper positioning of opening the air flow may be guided. Activity inside the room is to be carefully considered while locating the windows. Air should flow mostly through the most used areas of the floor space at body height depending on whether the inhabitants are sleeping in bed, sitting in chairs or standing. In Bangladesh where floor area per person is very small, rooms are extensively used for multiple purposes. So attempts should be made so that flow path of air reaches all the corners of the room horizontally and vertically from sleeping level(floor level) to standing level of about six feet height.

In double hung and horizontal sliding windows, only half of the glazed area is available for air flow. In vertically pivoted windows horizontal movement of the air can be controlled. Horizontal pivoted sash windows can suitably direct the air flow. But it decreases the flow to some extent as the angle of the sash with the horizontal increases. Horizontal projected windows direct the air upwards and is not at all suitable. Casement windows which are mostly used in Bangladesh are quite satisfactory from the air flow point of view. It seems single leaf casement windows, opening outside would be more effective. It may be mentioned that windows with fixed glass are useless in Bangladesh context and should never be used.

Vertical position of inlet window is most critical. Because of forces of inertia flow pattern of air through the space is mainly determined by its direction on entering. Position of the outlet windows slightly affect the flow and velocity pattern of the indoor air. A change in sill height may significantly alter the velocity at certain levels though the average air speed of the whole space may not change appreciably. (15)

Placement of the horizontal location depends on the configuration of the building and position of external objects. It should be placed where maximum inlet velocity will be available. The internal function of the room should also be noted.

A higher indoor air velocity will be obtained when inlet and outlet windows are located in narrow walls of the room, where the air travels the longer path. If the windows are put in the wider walls the indoor air velocity become reduced. (fig. 19)

Permanant openings are to be provided in a hot humid situation like Bangladesh. In driving rains when all the doors and windows are to be closed these work as exhaust. In winter when all the doors and windows are closed these provide for health ventilation, Permanant openings below sill level and above the window, with outward sloping louvers, protected with some kind of wire net, seem to be a good idea. But these should be provided on the South side, that is the summer wind direction only.

36	24	24	[illegible]	[illegible]
31	26	25	24	53
29	24	27	39	70
30	(i)27	27	107	28
24	26	71	152	29

44%

35	43	52	45	48
36	35	33	31	56
34	25	31	39	55
32	23	30	45	38
33	67	60	61	62

42%

68	36	37	31	72
44	44	29	29	50
37	25	29	29	36
33	25	31	29	30
34	29	31	29	37

38	32	27	52	121
42	42	29	61	128
56	35	29	71	103
56	28	48	61	118
57	32	56	56	137

86	54	30	63	77
54	29	31	25	63
43	32	30	34	78
49	35	35	37	78
59	34	32	30	32

44	35	58	67	77
56	32	30	85	88
59	32	30	85	88
67	34	43	102	109
55	52	76	78	115

Fig. 20. Distribution of internal air speeds (% of external speed) with different inlet outlet sizes and wind directions.

4.2.6. WINDOW SIZES:

It is evident that air flow through a room depends on the sizes of windows. The effect is more prominent when there is cross ventilation and when the direction of wind is oblique rather than perpendicular. Sizes of windows change both the avarage velocity and maximum velocity of the interior. Effect of the size of windows become considerably less when only one of the walls have openings.(15)

When the room is cross ventilated greater effect on the internal velocity is obtained by increasing the inlet and outlet sizes simultaneously. But the velocity does not increase by the same proportion as the increase in size of openings. The rate of increase is more when the wind is oblique than when perpendicular. When the wind is oblique to the window, there are greater variations in the air pressure along the width of the wall. Table 3 quantitatively show the effect of inlet and outlet window sizes on maximum and average velocities. The openings are shown as fractions of the wall and velocities are expressed as percentages of the outdoor air velocity.(15) The distribution of internal air speed is shown in the fig.20.

It seems that both inlet and outlet window sizes close to two third of the full length of the wall give optimum velocities. The table also show that average indoor velocity depends mainly on the size of the smaller opening independent of its being inlet or outlet, whereas relative sizes of the inlet and outlet

WIND DIRECTION	OUTLET SIZE	INLET SIZE					
		1/3		2/3		3/3	
		AVARAGE	MAX.	AV.	MAX.	AV.	MAX.
PERPENDICULAR	1/3	36	65	34	74	32	49
	2/3	39	131	37	79	36	72
	3/3	44	137	35	72	47	86
OBLIQUE	1/3	42	83	43	96	42	62
	2/3	40	92	57	133	62	131
	3/3	44	152	59	137	65	115

Effects of inlet and outlet width on average and maximum velocities (15) (percentage of external wind speed)

CROSS VENTILATION	LOCATION OF OPENINGS	WIND DIRECTION	TOTAL WIDTH OF OPENINGS			
			2/3 OF THE WALL		3/3 OF THE WALL	
			AV.	MAX.	AV.	MAX.
NONE	SINGLE OPENING IN PRESSURE ZONE	PERPENDICULAR	13	18	16	20
		OBLIQUE	15	33	23	36
	SINGLE OPENING IN SUCTION ZONE	OBLIQUE	17	44	17	39
	TWO OPENINGS IN SUCTION ZONE	OBLIQUE	22	56	23	50
PROVIDED	TWO OPENINGS IN ADJACENT WALLS.	PERPEN.	45	68	51	103
		OBLIQUE	37	118	40	110
	TWO OPENINGS IN OPPOSITE WALLS.	PERPEN.	35	65	37	102
		OBLIQUE	42	83	42	94

Effects of cross ventilation on indoor average air velocity (percentage of outdoor velocity)

Table. 3.

have a pronounced effect on the maximum velocity.

When inlet is small and the outlet is large concentrated air flow of maximum velocity is obtained, because it gives rise to 'venturi effect'. This is shown in fig(21). When the inlet is large and the outlet is small air velocity in the room is reduced though the total air flow in the space is not reduced.

4.2.6. CONTROL OF OPENINGS:

Canopies, sashes and louvers and other shading and protecting devices are essential elements of a building in hot humid Bangladesh. These influence the indoor air flow pattern considerably. Canopies may eliminate the pressure build up above the window. So the pressure build up below the window level will drive the air flow upwards. This can be eliminated by keeping a gap between the wall and canopy. A gap of four to eight inches is desirable. The magnitude of pressure above the window govern the direction of air flow. At times adequate space is not available over the window. A parapet is helpful in such cases, specially when low celing and flat roof exist.

Louvers also create problems. The position of blades slightly upwards, which is necessary to keep off water, may direct the air upwards. So it is better to avoid horizontal louvers in housing design as far as practicable. Venetian blinds might guide the air properly but invokes a considerable sacrifice of velocity and mass of air flow.

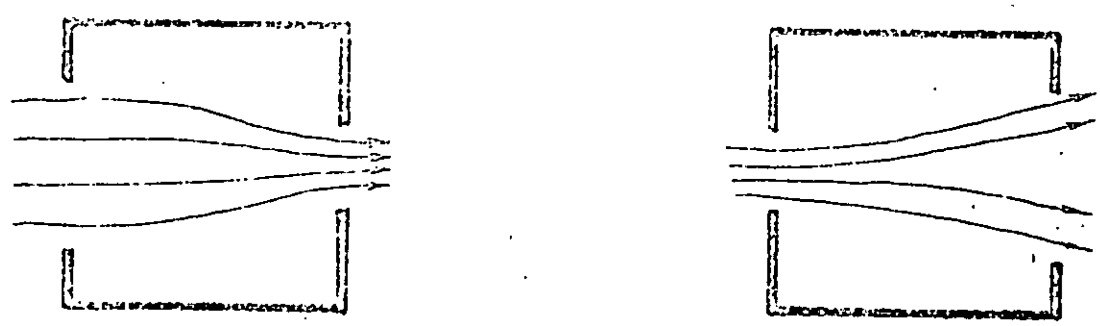
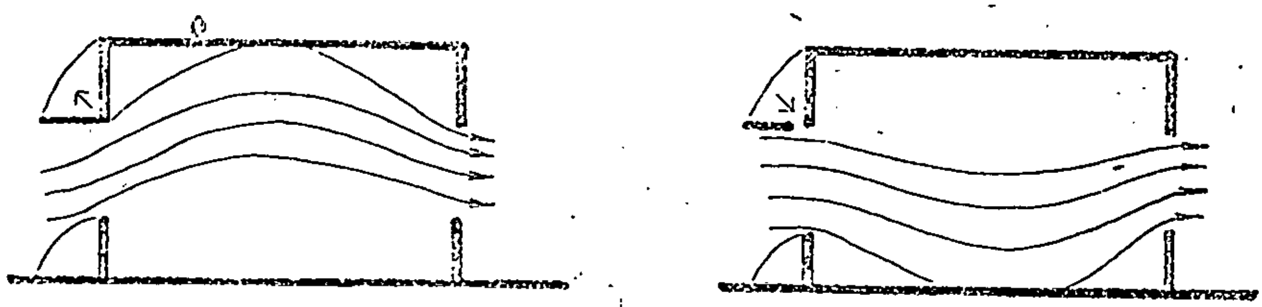


Fig. 21. Velocity is reduced with small outlet and large inlet. Increased velocity is obtained with larger outlet.



Canopy guides the flow upwards. Gap between wall and canopy guide the flow downwards.

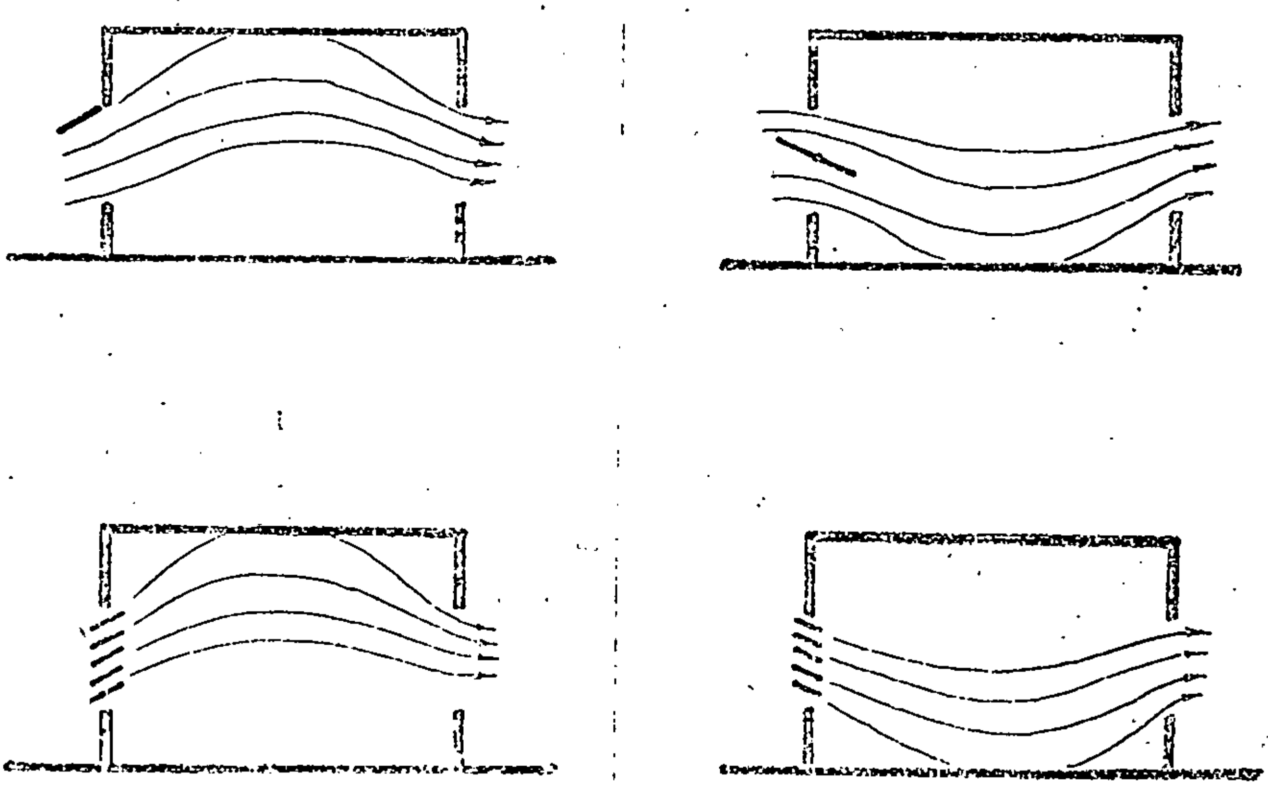


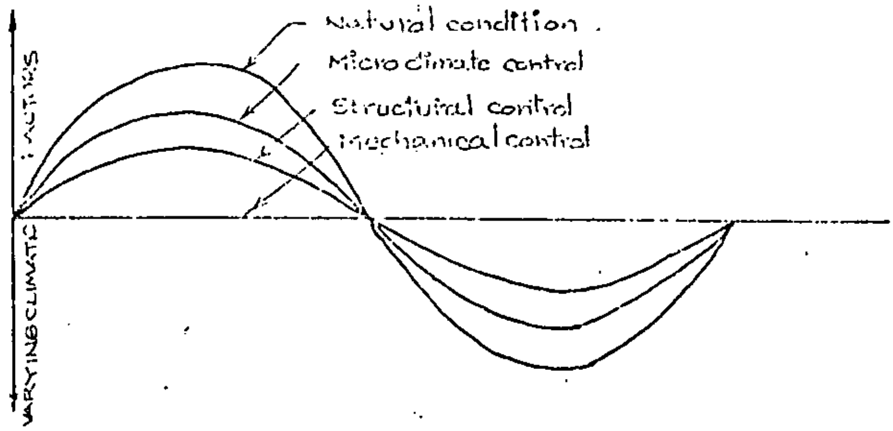
Fig. 22. Air flow may be properly guided with various devices.

In this connection it may be mentioned that hot humid climate is often associated with wind driven rains. Protection of opening is necessary. Making provision for proper air flow and also protecting from driving rain, together pose a problem. Koenisberger et al suggest that 'M' type of louvers can keep out water at wind velocities of 4m/s . With reduction of air velocities between 25 and 50 percent. However protective devices of this nature seem complicated and impractical.

In two storey buildings air flow pattern may be different in different floors. A solution which is satisfactory for ground floor may not be so for upper floor. A parapet wall may help the pressure build up above the first floor window; or some other device should be used to guide the air flow properly. Some of the above mentioned points are illustrated in fig.22.

CHAPTER FIVE. CHAPTER FIVE

5.1.0. Koenisberger (12) qualitatively expresses the extrinities of climatic variations that can be attenuated by various means by the curves shown below:



This goes on to prove that there is a degree upto which comfort level can be achieved by the means so far discussed. Further more it was found that shading devices, vegitation and other structural elements necessary for thermal control, sometimes work against the principles of proper indoor air flow.

5.2.0. VENTILATION REQUIREMENTS:

In hot humid climate as in Bangladesh evaporative cooling of sweat is the most suitable means to approach attainment of comfort level. For evaporative cooling massive air change and considerable indoor air velocity is required. About 10,000 cft. per hr. of air volume per person is necessary. If we consider three persons per room a volume of 30,000 cft. per hr. is necessary. This for a room of volume 10'.15'.8'. cft means about 25 air changes per hour.

5.2.1. Calculation of air change do not seem to be a preferable way of predicting air flow. Because as the evaporation of the body sweat saturates the air of the immidiate surrounding (humidity is already high), proper velocity is necessary to move the air of the surrounding to quicken the process of evaporation. A velocity as high as 300 ft. per min. may be required to keep the continuous processof evaporation without the discomfort of wet skin.

5.2.2. To give an idea of the air movement, 100 ft. per min. is slightly over 1 m.p.h. (one mile's per hour is 88 ft. per min.). This according to Beaufort scale (28) would slightly exceed the speeds under the classification 'calm'. A speed of 300 ft. per min. (approximately 3·5 miles per hour) would be under the classification of'slight breeze'. This speed will rustle leaves and can be felt on the face. Any speed more than that might hinder the normal function of the house by blowing paper or light objects.

5.3.0. NECESSITY OF MECHANICAL VENTILATION:

In Bangladesh air movements outdoors is not very much. Specially it is not so during all parts of the day. Sometimes the outside is very calm and air is still. Even with proper size and location of windows it will be a mistake to assume air velocities indoors to be more than 40 percent of the outdoor velocity.

5.3.1. To maintain this amount of air flow the layout of buildings should be atleast 2H distances apart. Required density may not be attained with with one or two storey buildings with such an open type of layout.

5.3.2. There are other climatic and social factors described below which discourage the provision of windows running along the full length of the wall. Besides provision for large windows increase the cost of the building. Even if generous provisions for windows were made they are not kept open for various reasons.

5.3.3. Lippsmeir says, "It isextremely tiring to stay in a room that admittedly is screened but the openings of which have a bright glaring background."* This is more intensified by the fact that it is not only the sun but the whole overcast sky acts as one source of glare. So despite of the fact that large windows are necessary for ventilation people tend to provide smaller windows. Even if large windows are provided they are kept closed.

5.3.4. Dust is a cause of annoyance in Bangladesh. So some sort of barriers are provided to cutdown dust. The barriers like high boundary walls, screens, curtains, etc. drastically cut down the air flow.

5.3.5. For reasons of privacy, noise and glare all the windows of the are heavily curtained. This also seriously disturbs the badly

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*LIPPSMEIER, G. "Building in The Tropics"
Callwey Publication, Munich-Germany 1969

needed air flow required for comfort. However no studies on the effects of curtains on indoor air flow were available. For reasons of security windows in Bangladesh are heavily grilled. This also cuts the air flow. In absence of data on its effect on air flow, reduction may be assumed to be equal to reduction in size of opening due to the projected area of the grilles. More serious cause of concern is that for reasons of security many people keep the windows closed at night.

5.4.0. CIRCULATING FANS:

Considering the above mention facts it may be safely assumed that some kind of mechanical means of ventilation is necessary to achieve tolarable comfort levels inthe indoor environment. As a matter of fact most of the govt. housing have ceiling fans, in the houses. The author did a case study of one of the oldest govt. housing in Dacca. The 'C' type housing which may be classified as middle income group housing has ceiling fan in two rooms of each flat. A plan and some survey data is given in the appendix 2. Usual practice is to put 36 inches to 56 inches fans suspended in the middle of the room. Some flats for higher income groups have 4 to 8 ceiling fans in every flat.

5.4.1. According to C.E.B.S. an increase in 30 f.p.m. in the rate of air movement appears to correspond in its effect to a reduction of 1°F in the dry bulb temperature of an environment. This effect is progressively increased up to 200 f.p.m. beyond which there is little or no improvement. High rate of air movement

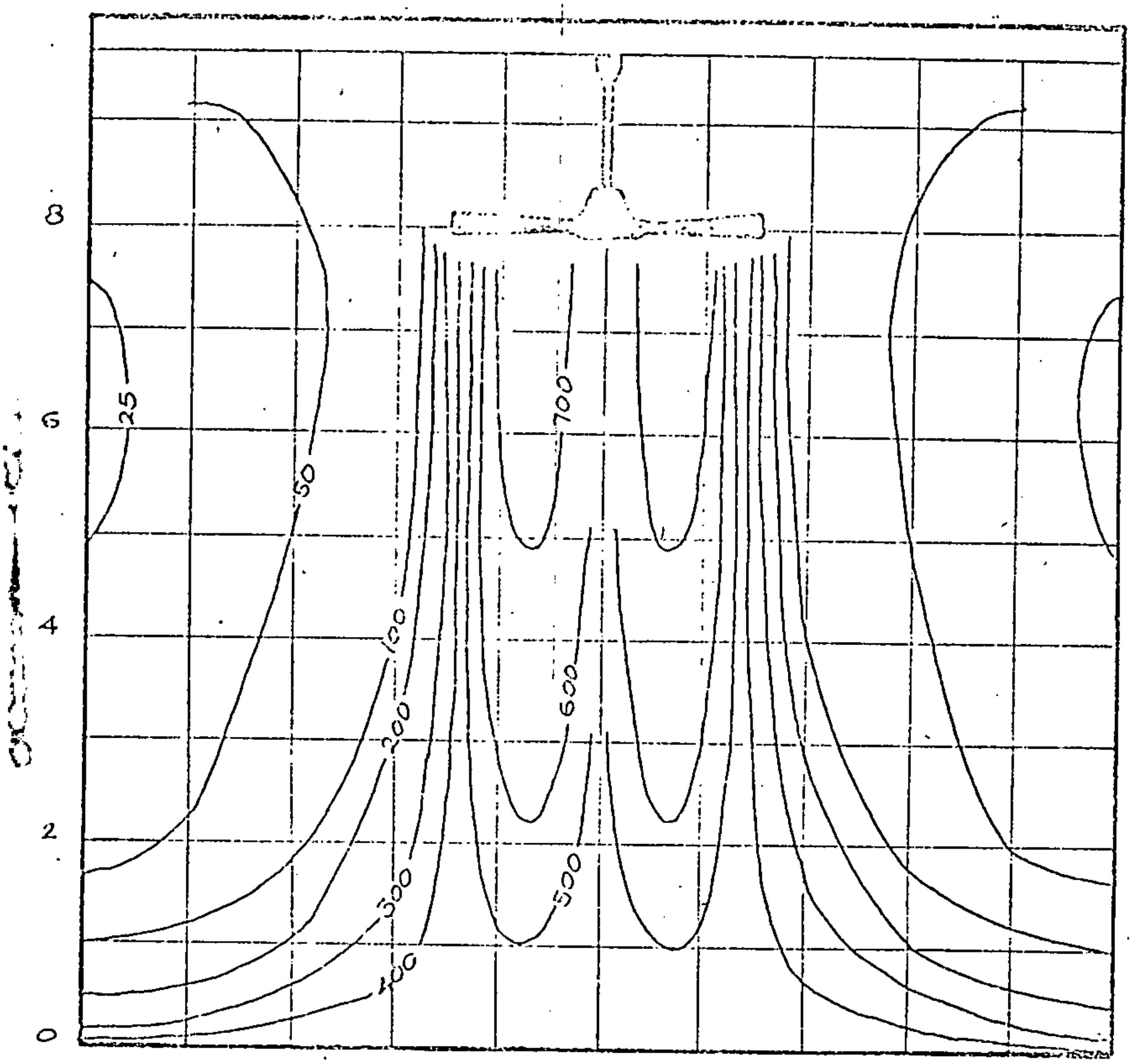


Fig. 23. Air velocity distribution for 36 inches ceiling fan.

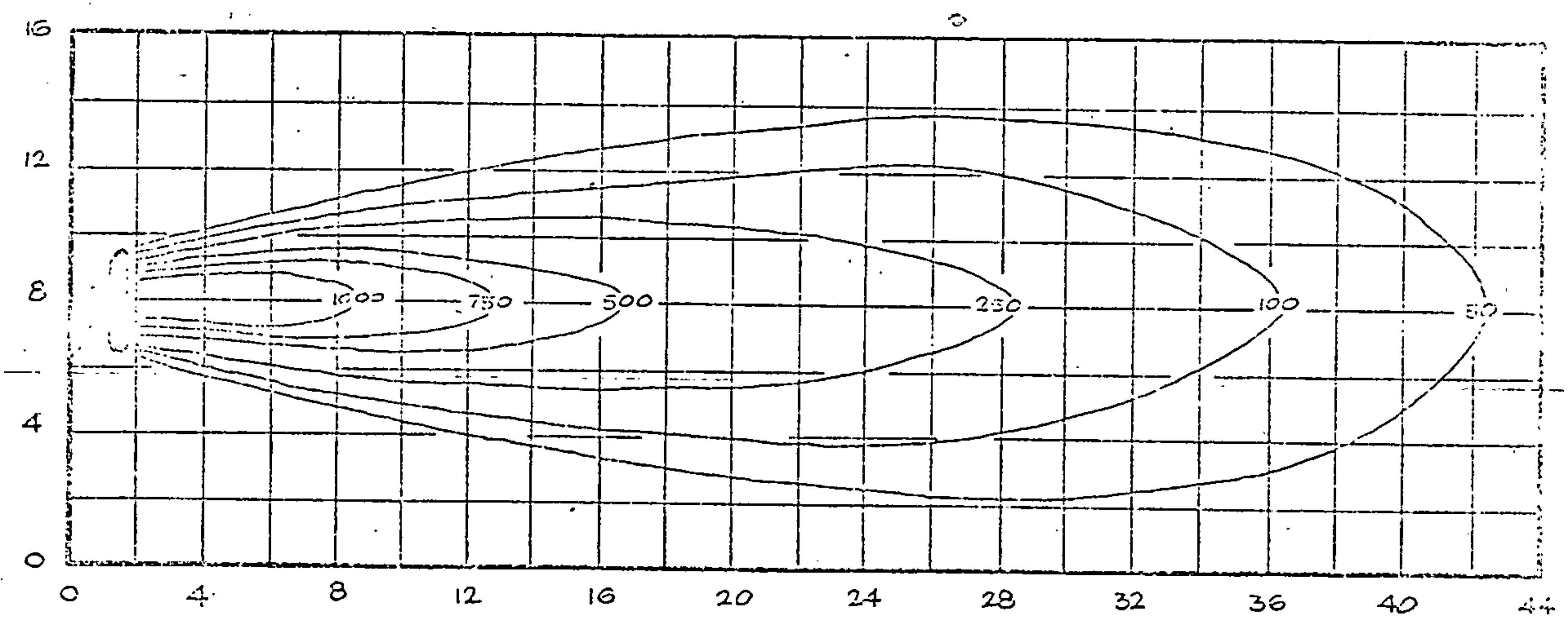


FIG. 24.

AIR VELOCITY DISTRIBUTION FOR 24" AIR CIRCULATOR at temperature much above 90° F can lead to net heat gain by the body because the heat transfar by convection often outweighs the effect of evaporative cooling. The velocity distribution diagram for a 36 inches ceiling fan and a 24 inches air circulator is shown in the fig.23 & 24. (29)

5.4.2. The disadvantages of circulating fans are:

A. It does not induce air change. It churns the air. It does not cool the surrounding air. Sensation of coolness is mainly achieved by enhanced evaporation from the skin.

B. At least one fan is necessary in every room.

C. Air velocity directly below the fan may be annoying.

D. May be noisy, specially at high speed.

E. Since it is suspended from the ceiling, height of the celing has to be increased.

5.5.0. MECHANICAL VENTILATION SYSTEM:

Usually in mechanical ventilation two types of fans are used.

A. Propeller type or axial flow fan.

B. Impeller type, centrifugal or tangential flow fan.

The installation take any of the following three forms.

A. Exhaust system: Where the indoor air is forced out and fresh air finds its way through grilles or openings. Indoors are under slightly reduced pressure.

B. Plenum system: Where air is forced in from outside through grilles and indoor air finds its way out through grilles. Indoors are under slightly increased pressure.

C. Balanced system: Where air is both supplied and removed by mechanical means. Mostly used when heated or cooled air is supplied. Most expensive system. (12)

5.5.1. The author suggests for Bangladesh situation an exhaust system with propeller type axial flow fan placed at a central location to draw air from all the rooms. The floor plan may be such that the rooms are placed around the space from where air is drawn directly so that no duct would be necessary for smaller houses. The intake of air is mainly through the windows. But there must be permanent openings preferably below window sill to ensure intake when the windows are closed.

5.5.2. Though an exhaust fan system is most often suggested for hot airid zones it seems equally suitable for a climate like Bangladesh, because it fulfils all the ventilation requirements. A very high indoor velocity of 300 f.p.m. may be obtained associated with upto 80 air changes per hr. for the whole house and a corresponding air change of up to 300 or more per hr. depending on the size of the room. The average diurnal range of summer months of March to September in Bangladesh is 14°F. So a reasonable amount of night cooling is also possible.

5.5.3. The author did not do any experiment, but has observed the use of this system in one or two places in Bangladesh and from personal experience has found the system very satisfactory. Most of the information given here is taken from the experimental study at C.H.E.S. done by E.T.WESTON published as special report 9 titled "Ventilation and Cooling a House With an Attic Exhaust Fan."

5.5.4. The experiment was done in a house the plan of which is given in the appendix 4. The structure was similar to a brick house. The fan was operated at air capacities of 5,000, 6,250, 8,900, 10,000, and 11,700 cft. per min. These were equivalant to producing rates of air change of 38, 43, 60, 70 and 80 per hour respectively for the house as a whole. The doors and windows of the house were fully or partially open during the experiment. The fan was run both continuously and for various durations of time. Various outdoor air velocities and directions were encountered during the experiment.

5.5.5. A table indicating air change in one room or group of rooms in combination, in relation to the whole air change of the house is given in appendix 4. A minimum of 155 air change per hr. is obtained in the combination of rooms for a whole air change of 80 for the house. This is more than adequate. The velocity also vary with air change, being higher in smaller rooms, When considered in combination the velocity is close to number indicating air change. It seems a velocity of 300 f.p.m. very easily considering one room at a time or two rooms say two bed rooms at a time. The velocity is slightly affected by the windows remaining partly or fully open. But the fluctuation caused by the outdoor air velocity is often helpful. Because when a constant air velocity is obtained, experience indicate that a higher rate is requred than if the speed is fluctuating to produce the same awareness of air movement. For night cooling by outdoor air, it is observed that fall of the indoor temp. is approximately 85 percent of the rate of fall of the temp. of the outdoor air. The temp. of the surfaces of partition, etc. are also reduced, but at a slower rate than the air temp. The minimum area of the inlet of the fan recommended by U.S. studies (30) is 14·75 sq. ft. for a fan rating of 10,000 c.f.m.

5.5.6. The system per forms most efficiently when it is run continuously. Intermittent swiching on and off of the fan at short intervals of time is not satisfactory. Switching the fan off often, in order to reduce the consumption of electricity is not desirable. So it is advisable to use multiple speed motor to drive the fan though the initial cost may be more.

5.6.0. ADVANTAGES OF EXHAUST SYSTEM:

The advantages of the exhaust fan system over circulating system are following.

5.6.1. It can induce air movement along with air changes. So it does not only move the air but bring in fresh air.

5.6.2. It may bring the indoor temp. of air and surfaces down by bringing in cool outdoor air when the outdoor temp is considerably low, specially at night.

5.6.3. It need not limit the activities of the occupants of a house to the same degree as would a circulating fan, because air can be induced throught a room or group of rooms and not within a restricted area only.

5.6.4. In a centralised system less noise will be perceptible the source (fan) being away from the rooms.

5.6.5. It is economic in comparison with circulating fans, because in a flat usually number of circulating fans are used.

5.6.6. It is possible to layout the structures more closely to one another to meet the required density level, with low rise buildings. The rules of open type layout to ensure a suitable outside air velocity need not be adhered to.

5.6.7. It gives more freedom to the arrangement of rooms. Only single banked arrangement of rooms are suitable to ensure reasonable ventilation by natural means. In this case a double banked arrangement may be used efficiently. Economy of space may be achieved by designing compact floor plans.

5.6.8. The surrounding of the house may be profusely planted. This will cut down the radiation heat gain and keep the outdoor air temperature low which in turn will help to bring down the indoor temp. within the comfort level. Under conditions of natural ventilation profuse planting cut down the inlet air velocity appreciably.

5.6.9. Orientation can give maximum cosideration to solar radiation. A little deviation from the optimum orientation from ventilation point of view will not be critical under exhaust fan system. Fortunately for Bangladesh North-South orientation is suitable from both solar radiation and natural ventilation point of view.

5.6.10. Room height need not be excessive. A height of eight feet is satisfactory because no extra height for the fixtures like cerculating fan would be necessary.

5.6.11. In future if need arises blow fans may be used to force air inside to make the system even more efficient.

5.7.0. SPECIFICATIONS FOR BANGLADESH:

Wickham, F. suggests that the nominal air handling capacities are 2,200, 10,000, and 14,000 cft. per min.; the average wattage 75, 220, and 250 and the cost 64, 70 and 80 Australian dollars (1963). (31) In case of Bangladesh for a house plan shown (fig.25) a 10,000 c.f.m. capacity of 36 inches unit may be suggested.

5.7.1. The outlet of the exhaust fan should point towards North or West that is away from the prevailing summer wind direction. Because prevailing wind interferes with the exhaust flow.

5.7.2. Preferably a dual or multiple control fan be used. The initial cost may be high but in the long run will prove economic because of saving in electricity due to running at lower capacity.

5.7.3. The fan and motor should be well protected from rain. The motor may be placed at a distance from the fan in a well protected place and fan be rotated through a belt.

5.7.4. The area of the inlet to the fan should be more than 15 sq.ft. No obstruction like grilles should be placed in the inlet of the fan. The fan inlet from rooms usually placed on top of doors or at a high place, should be operable and should be closed at times when the room is not in use. This will increase the air velocity of the rooms in use at that time.

5.7.5. Permanent openings should be provided so that flow of air is not stopped even when all the windows are closed. Permanant openings may be placed under the window sill. Provisions may be made for closing the permanent openings during winter months. During winter when all the openings are closed, exhaust openings will provide adequate health ventilation.

Ventilation

5.7.6. It is not possible to specify exactly, without doing experimental studies under specific climatic conditions of Bangladesh The author hopes to do some experiments in near future. Based on some of the findings of this dissertation a floor plan for a typical house is shown. This will be developed during the design phase of the dissertation.

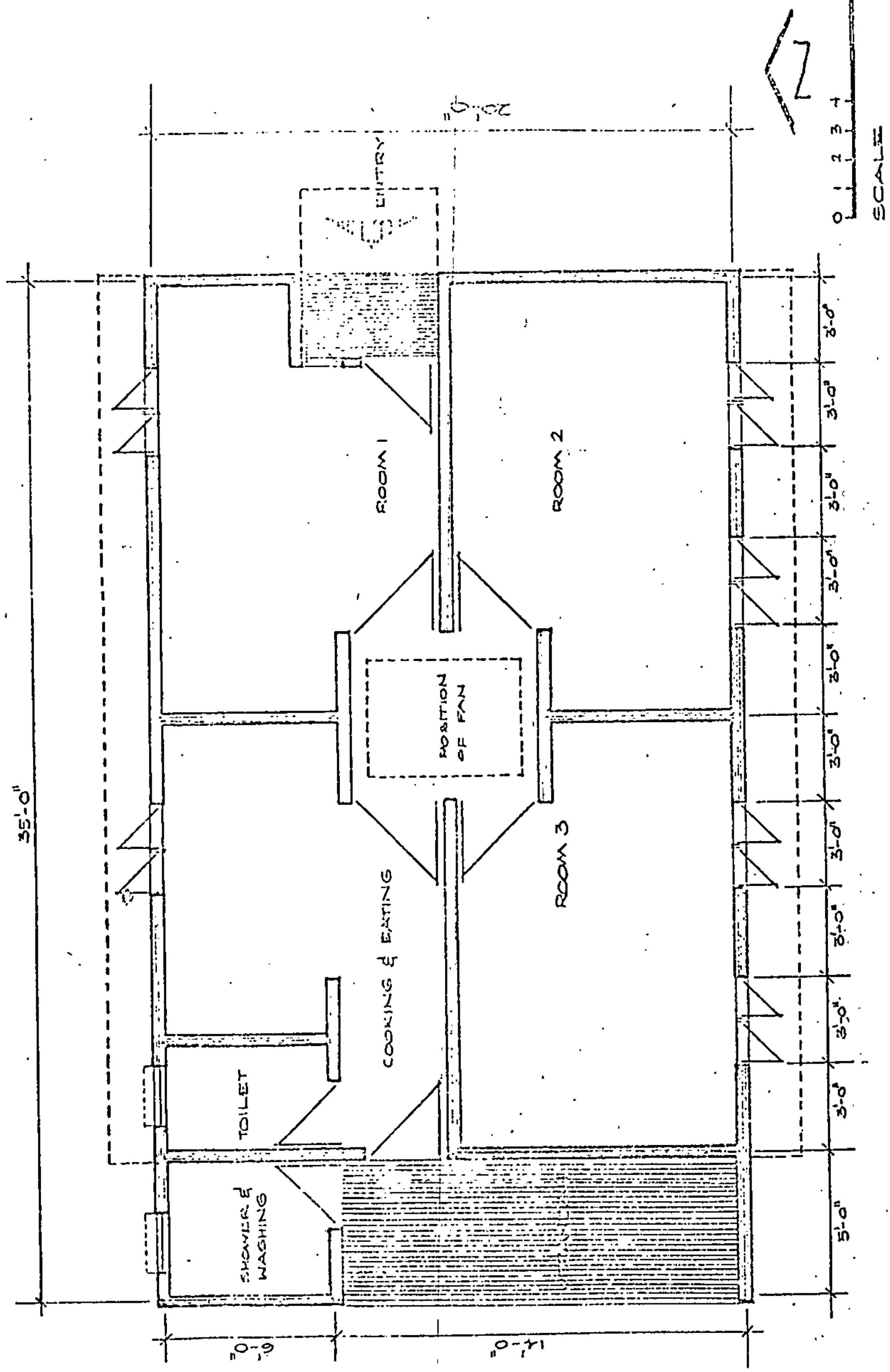


Fig. 25. Plan of the single storey house with exhaust fan ventilation system.

5.7.7. The exhaust system can also be efficiently used for multi-storey buildings. In every floor an air handling space is required which is connected to a vertical shaft, alternately ducts may be used.

The plan of a single storey solution is given (fig. 25). All the spaces are grouped around a central hall ober which the exhaust fan is placed. It has a covered area of 700 sq.ft. The solution is for middle income group of people of Bangladesh. This will be soecially suitable for high density urban residential areas.

CHAPT R SIX CHAPTER SIX

6.1.0. The theme of the dissertation may be devided in to three parts; to identify the problem, to determine the ventilation and air flow requirements (both velocity and air change) and to determine the means to achieve the required air movement.

6.1.1. Chapter one gives the available climatic data. Analysis of the data is partly done in chapter two. The comfort condition desired and how far off Bangladesh situation is from the desired level is found out. It is also seen with reasonable clarity how well or worse off the internal environments in the buildings are, as far as comfort is concerned from the climatic point of view. Chapter two together with chapter three helps also to determine the requirements in sufficient objective terms if not in exact quantitative terms. Chapter four and five give some ways and means to achieve the required air flow.

6.1.2. All the data that would be necessary for identification of the problems were not available. Data on vapour pressure at various times, hourly temperature values, exact day and night situations, frequency of deviation from the mean values etc. would be helpful. Besides climatic data informations present housing situation, social, cultural and economic condition of people, availability of services are also given. From these it may be concluded that the question of density is over emphasized. A gross density of 100 to 150 should be sufficient. There is definitely a dual cultural standard among the people depending on the degree of western influence. Bulk of the city people still have their roots in rural areas. Their cultural values should be respected. Most of the housings fail to do so. Outdoor living is of vital importance in the climatic situation. So efforts may be made to give a small yard or patch of land to every family.

6.1.3. Given proper climatic data, it is possible to find out the air movement requirements with reasonable accuracy analytically. In chapter two, the effects of various objective and subjective factors on human physiology and comfort conditions have been discussed. The awareness of all the factors will not only help the designer to make provision of adequate ventilation but will also help make right decision about the other components of the house. For example, U value of the shell, the colour of the exterior etc. Though other thermal indices were discussed, Olgay's Bioclimatic chart have been used to compare the comfort conditions because it is simple and less detailed data is required. It is seen that in some periods comfort is not attainable without dehumidification. But it can be easily judged what measures will improve the situation and reduce the heat stress even if satisfactory comfort level cannot be achieved.

6.1.4. In chapter four various factors like orientation, cross ventilation, position and size of openings, control of openings and location of buildings in respect to one another have been discussed. Suggestions have been made about how to maximise air movement and direct it through the inhabited zone of the interior. Though it is possible to determine the requirements exactly, it is not possible to predict the air movement exactly with natural ventilation system. Because some of the variables like external wind velocity and direction are not controllable. Other factors like air change and air velocity have also been discussed. It is stressed that air velocity is more significant than air volume or mass. In case of air velocity, avarage velocity is more important than maximum velocity. The need for proper distribution of air flow cannot be over estimated. Nature of distribution have been shown both in qualitative and quantitative terms in tabular and diagramatic forms. Contrary to present practice, the author emphasizes the need for permanent openings both for health and comfort ventilation.

6.1.5. Finally it is suggested that natural means do not adequately satisfy the ventilation requirements. From the case study it is seen that circulating fans are used in almost all govt. housing. Once the need for mechanical ventilation is established, next step is to find a suitable system. It is seen that 300 f.p.m. of air velocity and 100 air changes per hr. is the optimum air flow requirement. Anything above that will not improve comfort conditions appreciably. With centralised exhaust fan system this can be attained. The advantages and specifications have been thoroughly discussed but financial aspects could not be analysed. The system does not assume a closed condition; ventilation is assisted by the exhaust fan. A floor plan of a single storey flat with a exhaust fan system has been shown. This along with a two storey solution will be developed during the design phase.

CORRECTIONS

A. The name Koenisberger should be rightly spelled as KOENIGSBERGER. It occurs in

Page	Line
9	9,24
19	12
40	4, 21
56	4
57	1

B. Page 54 line 8 word 1 should read WHEN.

C. Page 64 comes after page 62. There is no page 63.

METHODS OF MEASUREMENT

Methods of measuring some of the environmental variables are given below:

A. AIR TEMPERATURE.

Air temperature can be measured by a mercury thermometer, a thermo couple or an electrical resistance sensor. Temperature of air is measured in degree Celsius or C. The simplest way to reduce the radiant error is to make the sensor as small as possible as the convective heat transfar coefficient rises with decreasing size, while the radiant heat transfar coefficient is constant. The dry bulb or true air temperature is a value taken in the shade, the thermometer being mounted inside a louvered wooden box known as the 'Stevenson Screen" at a height of 1·2 to 1·6 m above ground.

B. AIR VELOCITY:

The instrument most commonly used is the thermal anemometer. The heated probe can either be relatively large 3 to 6 m sphere which thus averages the velocity fluctuations with time so that mean value is measured or it can be quite small (a 5 hot wire) in which case it measures the instantaneous velocity. For less exact measurements the smoke technique can be used timing the movements of a smoke puff. Smoke ampules of various and types are available. Propeller anemometers are also used. The unit is m/s.

C. MEAN RADIANT TEMPERATURE

Because of its simplicity, the globe thermometer has been the instrument most used for the determination of mean radiant temperature in practice. It consists of a black spherical shell in the centre of which is placed a thermal sensor which take on the mean temperature of the globe. Spherical diameters of varying sizes have been used. But most common are Vernon's (d=15.2 cm) and Missenard's (d=9 cm). In theory any diameter can be used, so long as calibration is made; but a large sphere gives better accuracy since convective heat transfar coefficient is then lowest. Previously copper shells were used but these have an undesirably high time constant. Instead thin plastic bubble or balloon may be used. These are usually blacked by thin paint.

D. AIR HUMIDITY

Humidity will normally be the same over the whole area. It is therefore sufficient to measure the humidity at one location only. The measurement can be taken with a psychometer, dew point apparatus and hygrometer. The simplest way is to use dry bulb and wet bulb thermometer. Two ordinary thermometers are mounted side by side. First one measures dry bulb temperature. The bulb of the second one is covered with a gauze and is kept wet. This gives the wet bulb temperature. From these two readings humidity can be found out.

Another indication of atmospheric humidity is vapour pressure.

$P_a + P_v = P$ Where P is the atmospheric pressure

P_a partial pressure of dry air and P_v is partial vapour pressure.

The unit is Newton per metre square N/m^2

1 milibar = 100 N/m^2

The relation ship of all these quantities, that is dry bulb and wet bulb temperatures, absolute and relative humidity and of vapour pressure is shown by the psychometric chart.

CASE STUDY

The area of the case study is in Dacca. The site has a central location. The housing scheme was done during the period 1948-51. At that time it was at the edge of the town. Now with the expansion of the city, it has become the central location. Place of work, schools, shops, hospitals etc. are all very close to the site. This housing being one of the first major projects, many of the facilities were later placed near the site.

The site is flat without any undulation. Surface water drainage is done through open channel or drains. Drains are on both side of the road. These are very unpleasant and is potential health hazard. Drains are not well maintained. All other services are similar to the ones described in the article under urban housing in Chapter 1.

The toatl area of the site is 65 acres. Poulation of the site is 5100. Gross density is about 80 persons per acre. On western side of the site is grave yard, on the east is a girls' college; on the north is the New Market, a major retail shopping area of the city; on the south, is a boys school and private residences.

There are three kinds of roads, according to intensity of traffic. Primary with rather heavy traffic, divides the area into ~~three~~ three parts. Further sub-divisions are made secondary roads, tertiary roads and mainly pedestrian and access roads. It is interesting to note that at different times attempts were made to control in road by controlling entrance and exits. This shows that the road layout is not at all satisfactory.

The layout seems to be completely arbitrary. It seems that a few 'C' Type buildings were put first and later on empty spaces were filled with other buildings. It is surprising that some of the orientations were grossly wrong about which average Bengali is concious.

'D' Type buildings seem to have been conciously put around a court. This idea was possibly derived from rural houses where four blocks are usually put at four sides of a courtyard. But they missed the point that there four blocks serve four different functions and form a house combined together.

Due to overcrowding, all areas of the house are used for sleeping; Except for exclusive bedrooms, beds are removed or rolled up during day time. Mosquito nets are used at the time of sleeping to keep off insects. Eating is also done in the kitchen on a mat or locally devised very low furniture with no western equivalent. All the members of the family do not eat at the same time, so small area is necessary for dining. Toddlers play all over the house. Grown up children usually go out in the afternoon to play. School-going children are supposed to study at night and in the morning. They sit at the study table for about four hours a day. Grown-up coaching students are common. Men go to work at 10:00 hrs. and come back at 17:00 hrs. Students are at school at the same time.

Total cost of the house and cost of the elements are shown in the maintenance chart. The average cost of maintenance is between 2.5% to 2.79% of the toatl cost of building excluding the cost of land. The maintenance cost does not include overhead. Maintenance cost is in some cases higher than the rent received from tenants. An estimate and break down of the maintenance cost have been shown. Some photographs of the buildings are also shown.

All the buildings were 3-storey at the time of the case study. Now all of them have been turned to 4-storey heights with the addition of one storey, a case of vertical expansion.

SURVEY FINDINGS

A. 66% of the people are entitled to higher class of dwellings than they are living now.

B. 80% of the people wants to use the roof for reception and other purposes.

C. 35% of the people expressed feeling of insecurity, specially people in the ground floor, mainly because of no feeling of possession of surrounding land.

D. 60% has arrangement for food preservation like refreigeration.

E. 60% think stairs are maintained properly. Other half think it is not maintained properly. Most people did not agree to take care of the stairs.

F. No body complained of distance of place of work. Maximum time taken to go to place of work is 30 mininutes. Most of the other facilities are also close.

G. 100% thought protection from rain water to be inadequate. There is hardly any attempt to protect from rain water.

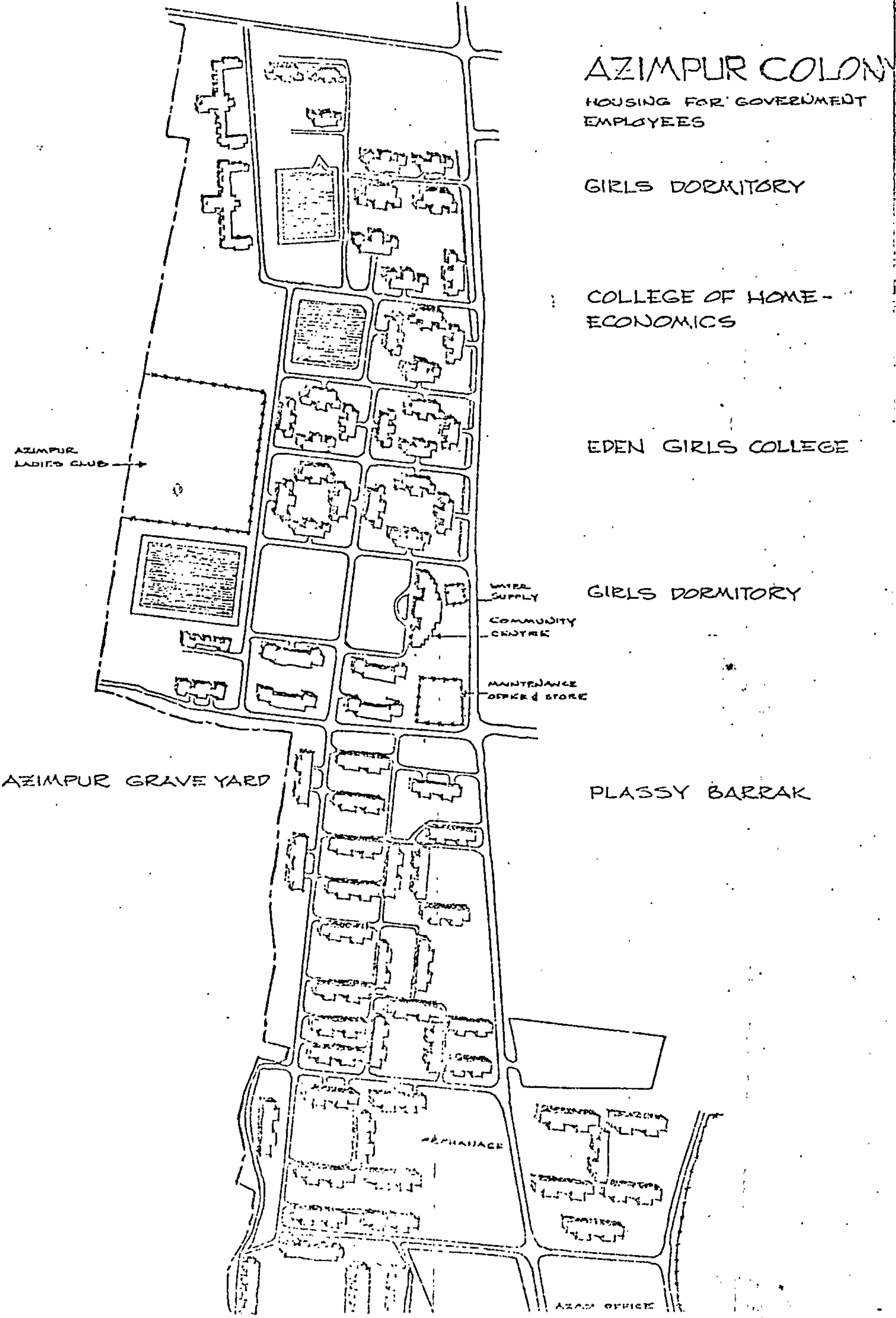
H. 66% thought all rooms would be uncomfortable without ceiling fans. Others think fans in bedroom only would be enough. All thought some kind of mechanical ventilation to be essential.

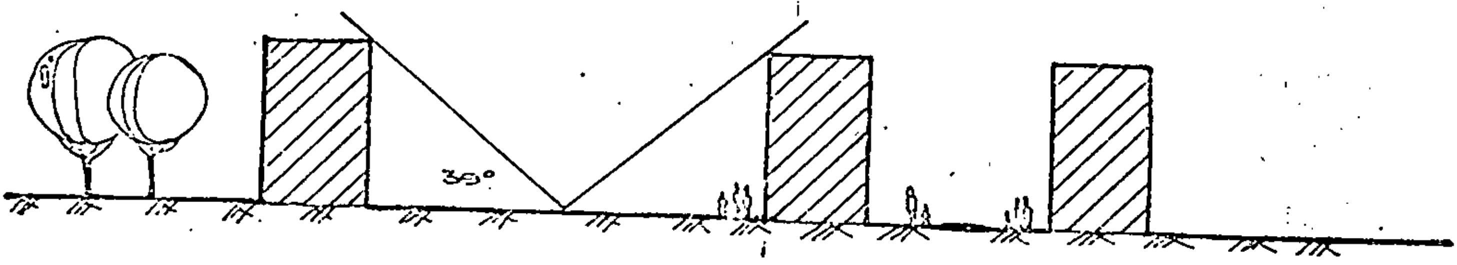
I. 100% of the people has at least one domestic help per family.

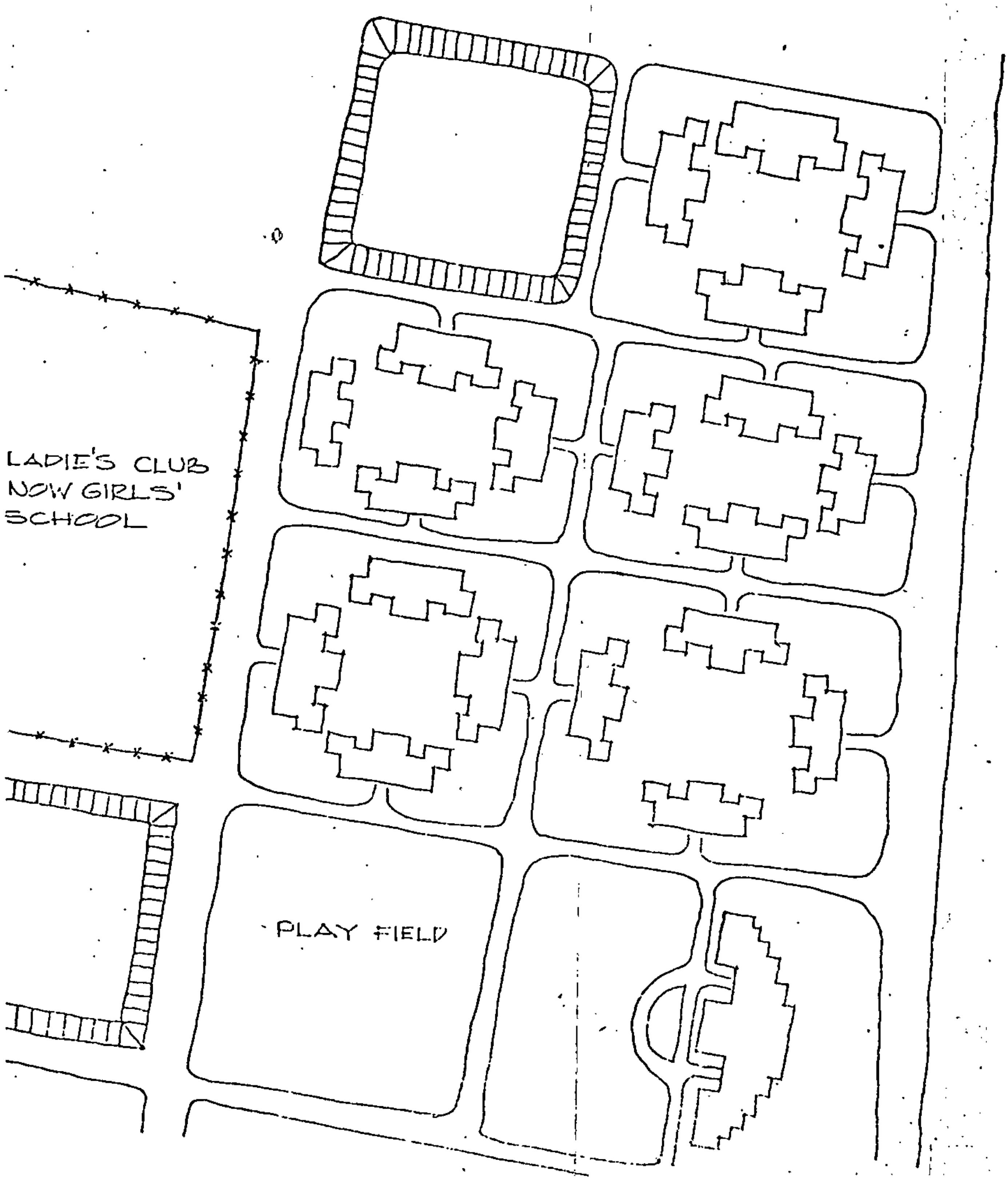
J. 60% of the people thought that waste disposal system was all right. Others believed it needed improvement.

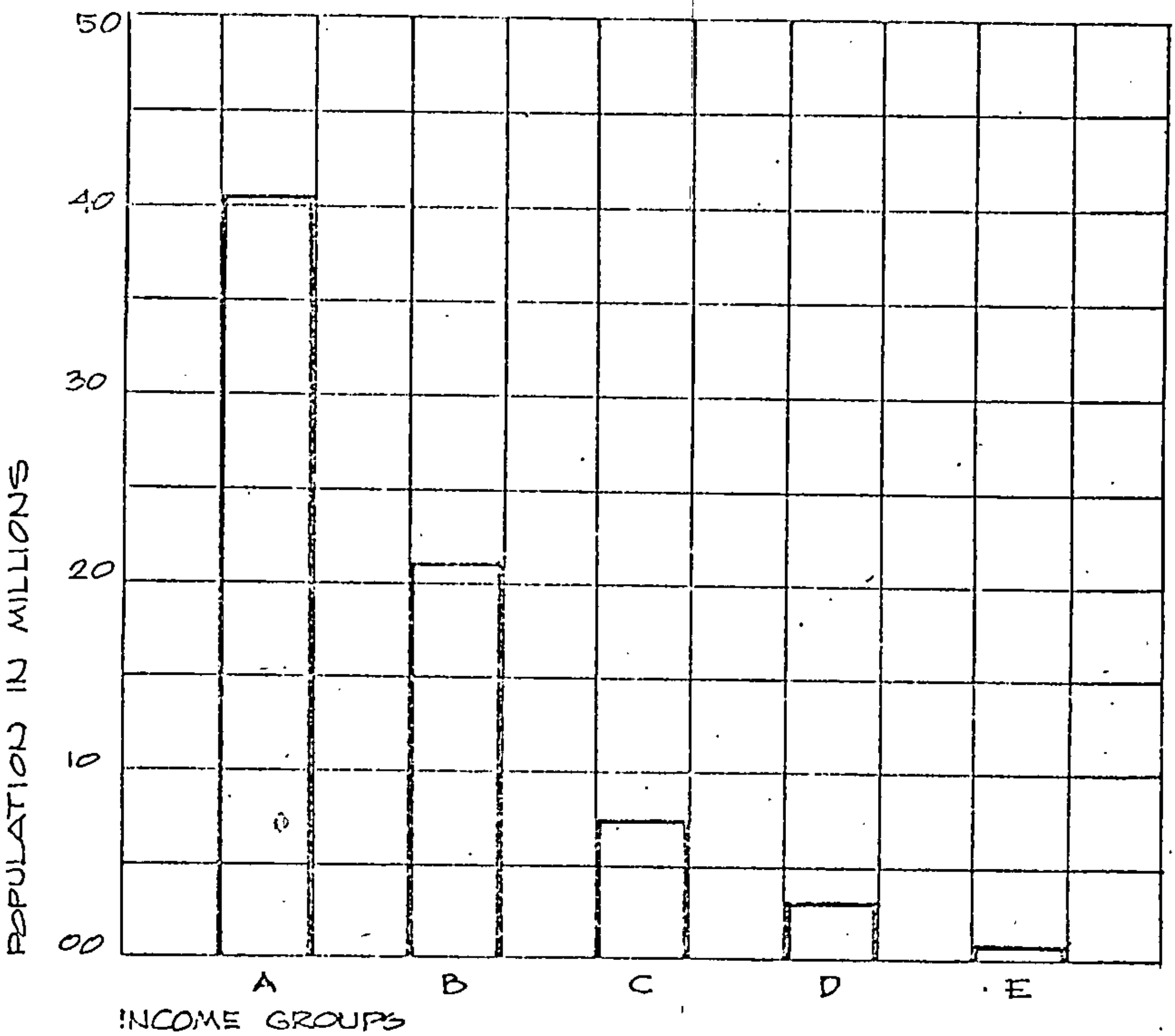
K. People did not seem to have clear idea about ventilation though they seemed to have clear idea about orientation. In the same building some thought ventilation was all right whereas others thought it to be poor.

L. Flats with bedrooms on the east side were preferred to flats with sleeping space on the west side.


AZIMPUR COLONY
HOUSING FOR GOVERNMENT EMPLOYEES
GIRLS DORMITORY
COLLEGE OF HOME-ECONOMICS
EDEN GIRLS COLLEGE
AZIMPUR LADIES CLUB
GIRLS DORMITORY
WATER SUPPLY
COMMUNITY CENTRE
MAINTENANCE OFFICE & STORE
AZIMPUR GRAVE YARD
PLASSY BARRAK

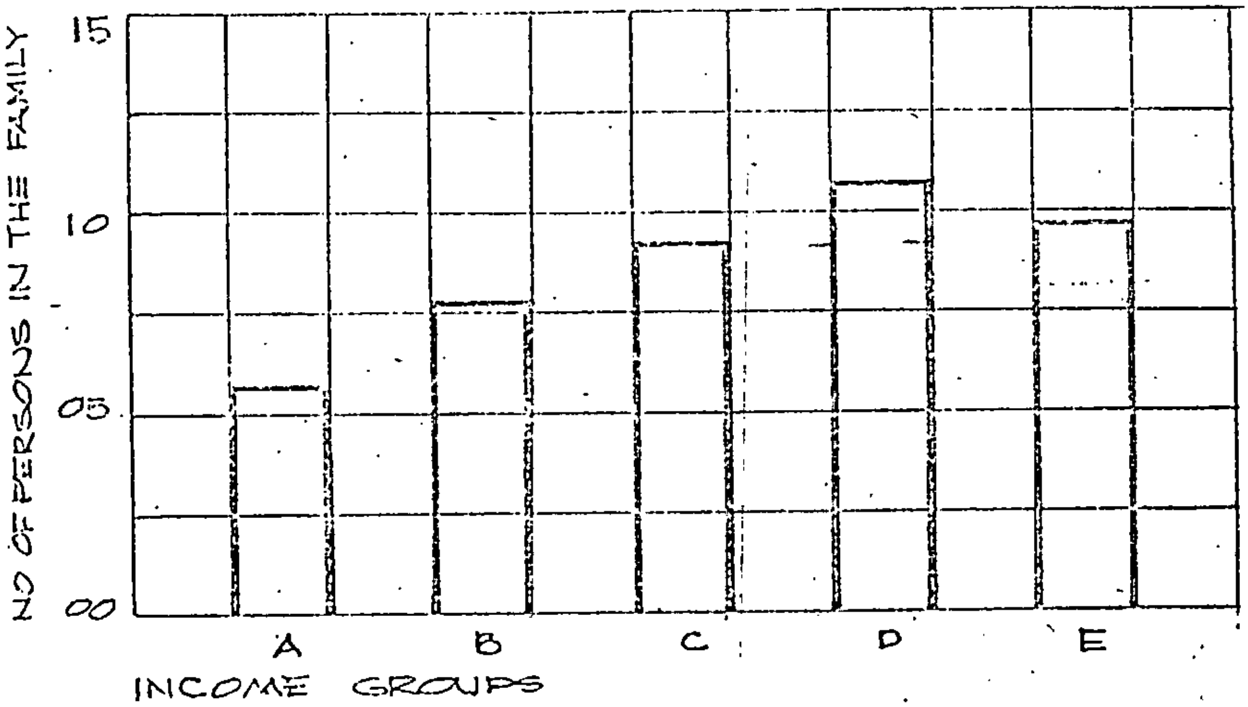

30°

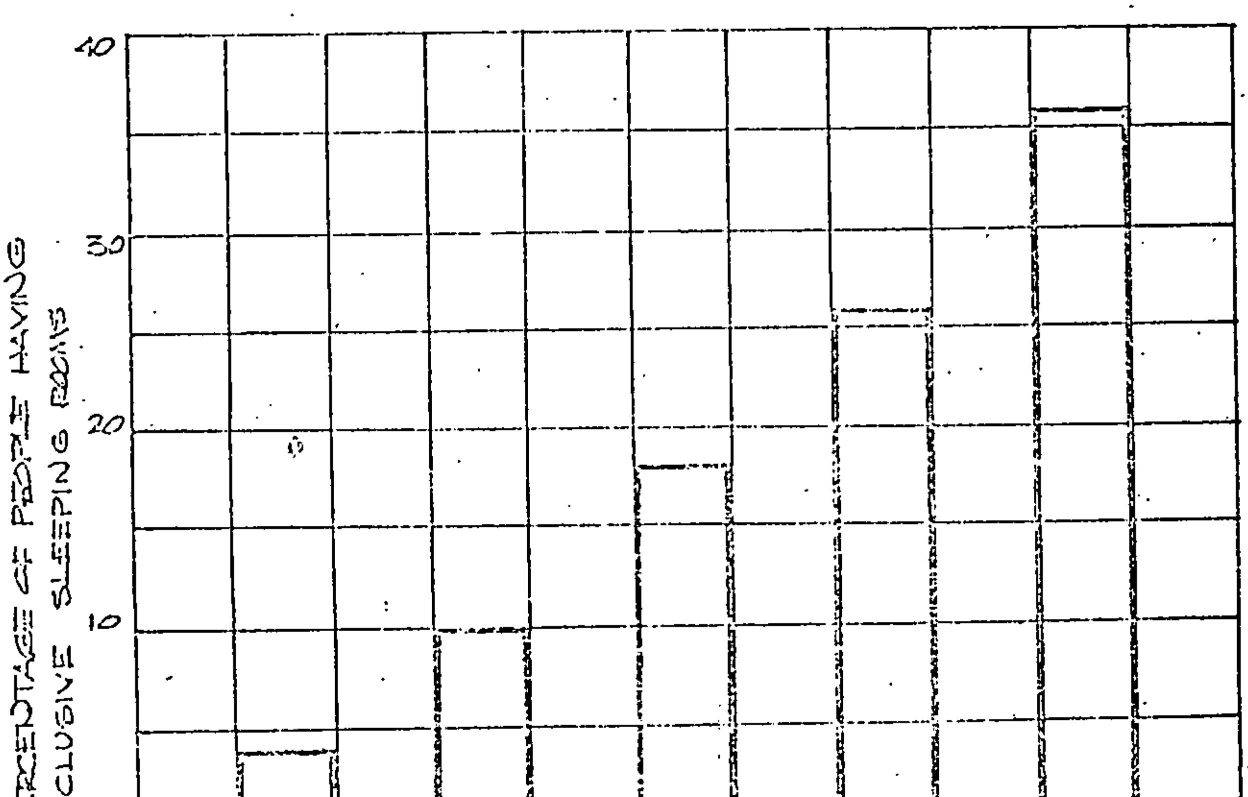

LADIE'S CLUB
NOW GIRLS'
SCHOOL
PLAY FIELD



NAME OF GROUP	INCOME PER YR UP TO		PERCENTAGE OF POPULATION
☐ A LOWER INCOME CLASS	TK 2400	£ 120	54
☐ B LOWER MIDDLE CLASS	TK 6000	£ 300	30
☐ C MIDDLE CLASS	TK 12000	£ 600	10
☐ D UPPER MIDDLE CLASS	TK 24000	£ 1200	05
☐ E UPPER CLASS	ABOVE TK. 24000	£ 1200 +	01

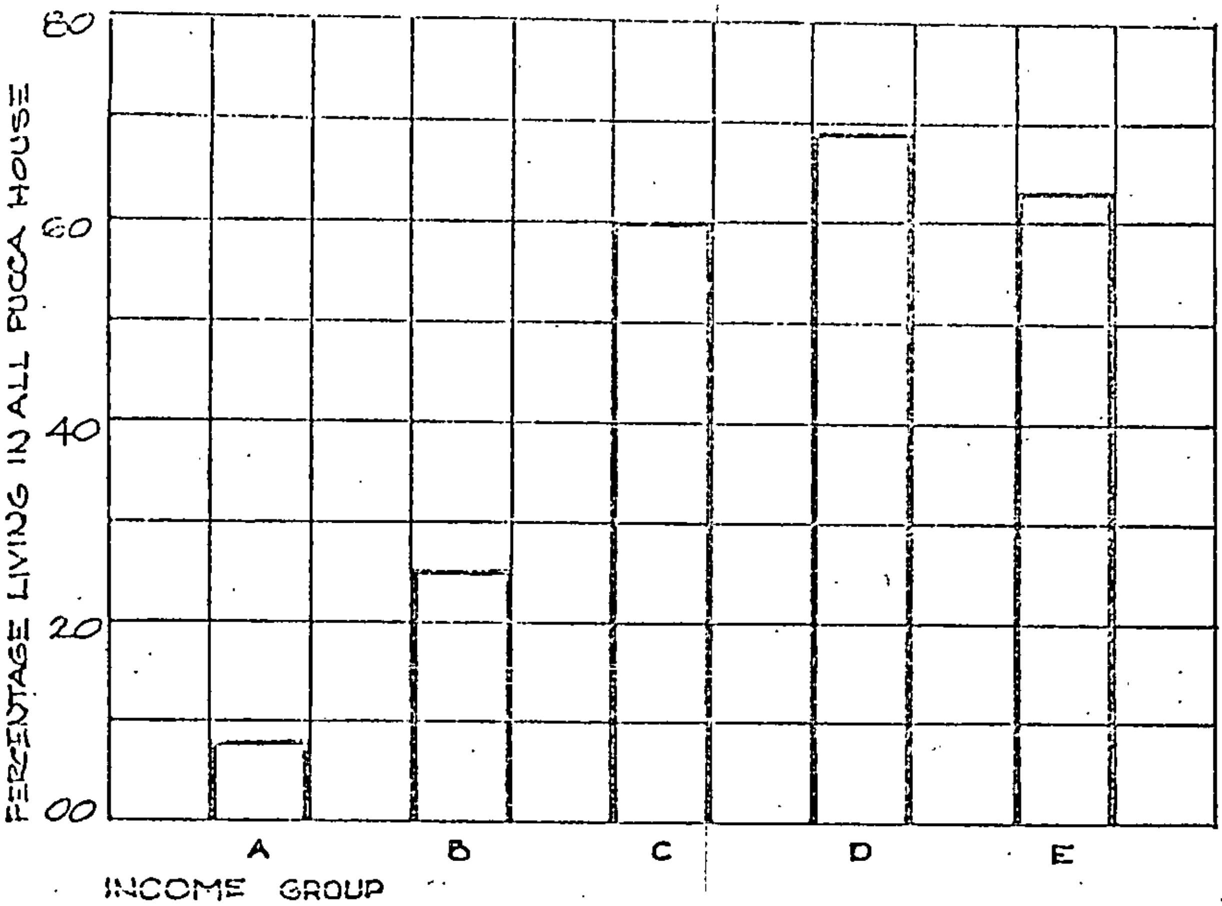
POPULATION IN VARIOUS INCOME GROUPS



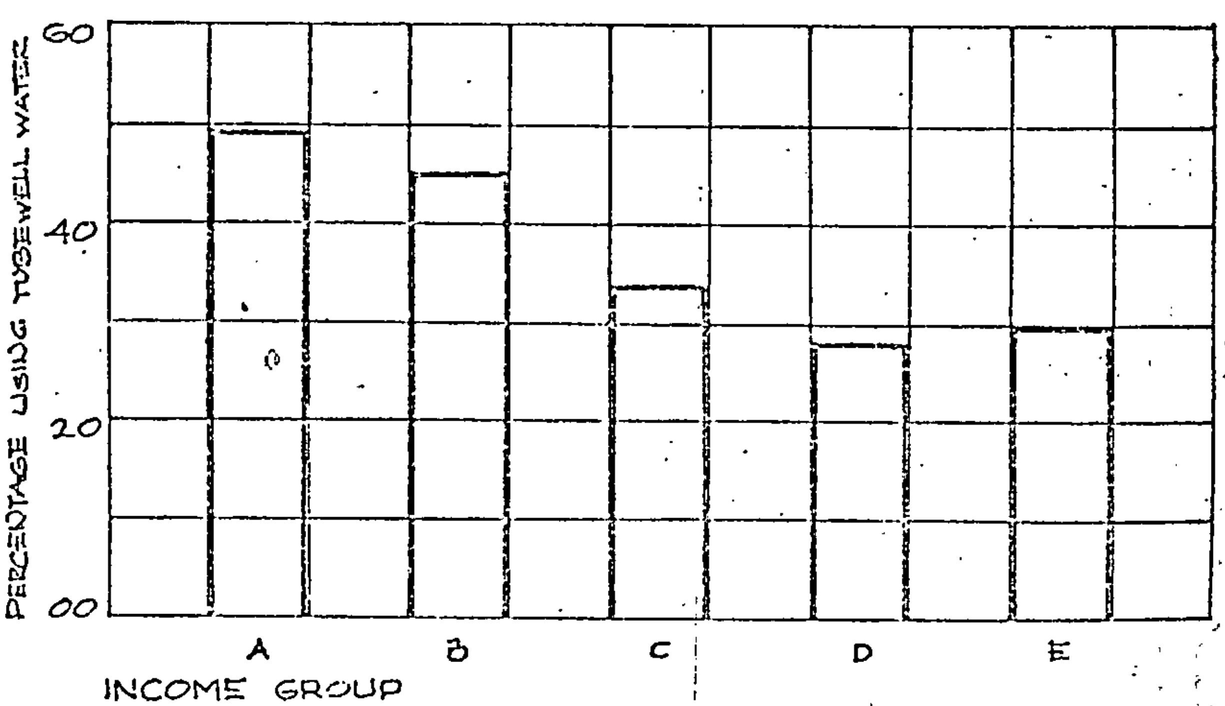


FAMILY SIZES IN DIFFERENT INCOME GROUPS

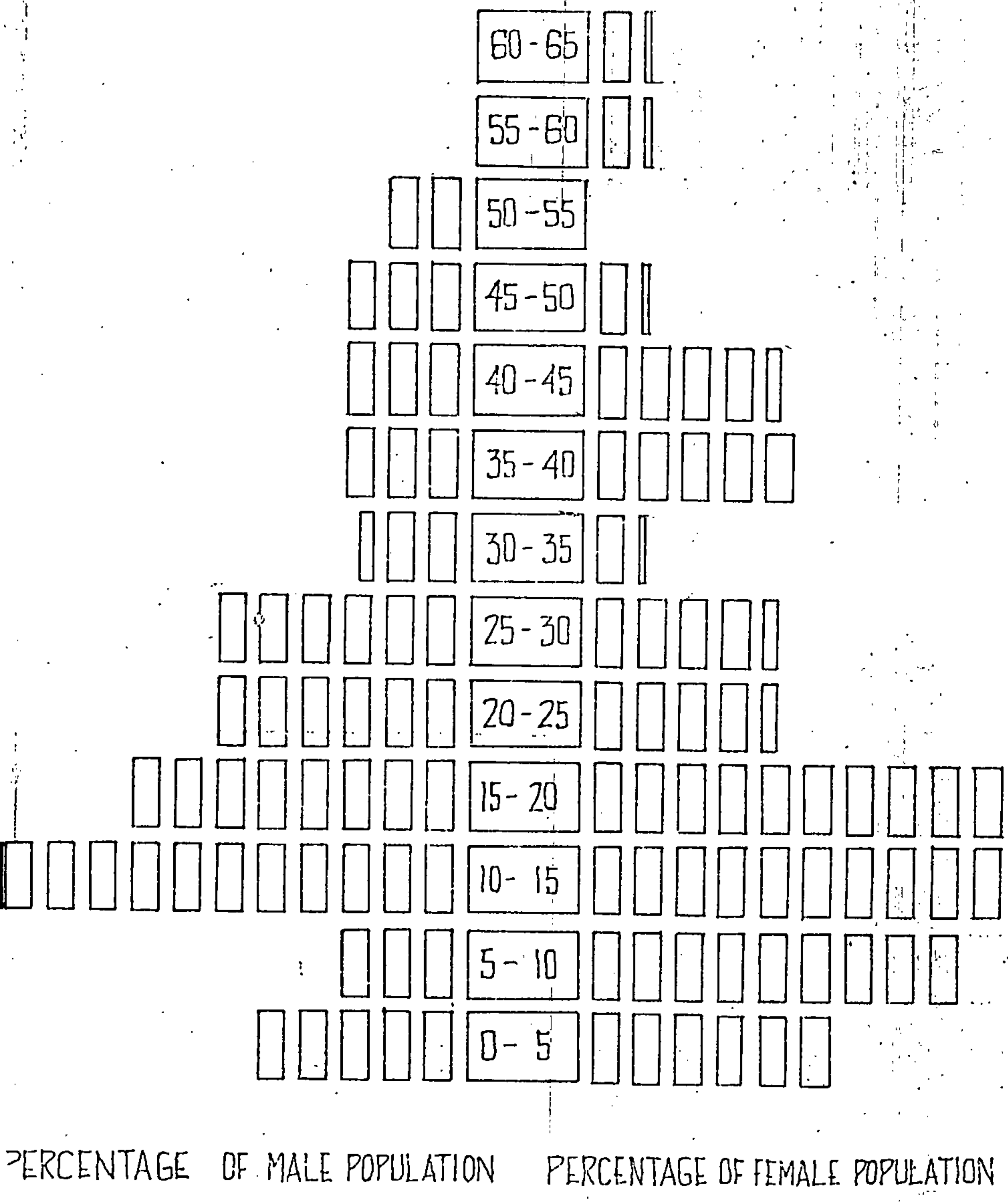
PERCENTAGES OF PEOPLE HAVING EXCLUSIVE SLEEPING ROOMS



% PEOPLE LIVING IN ALL PUCCA HOUSE

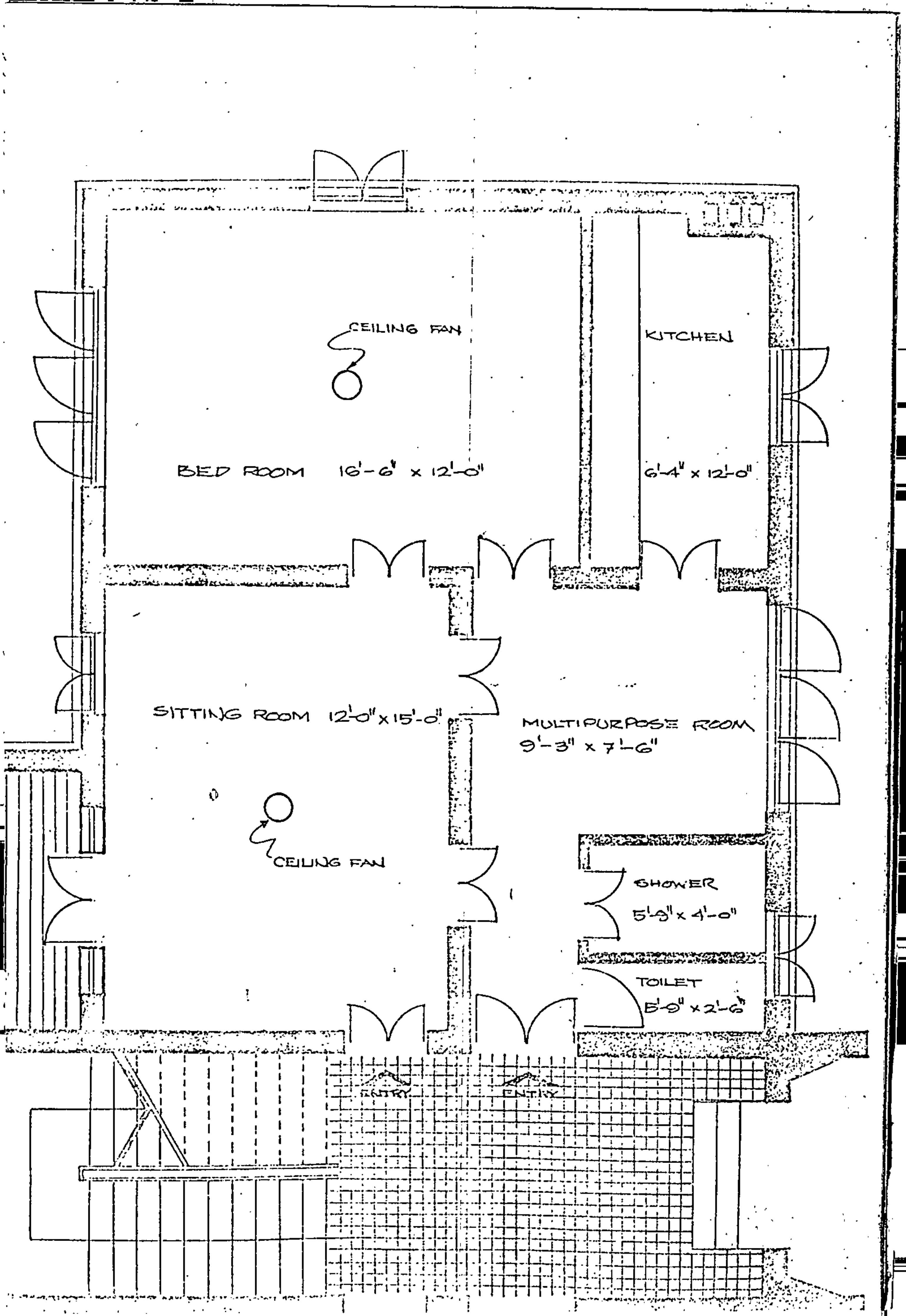


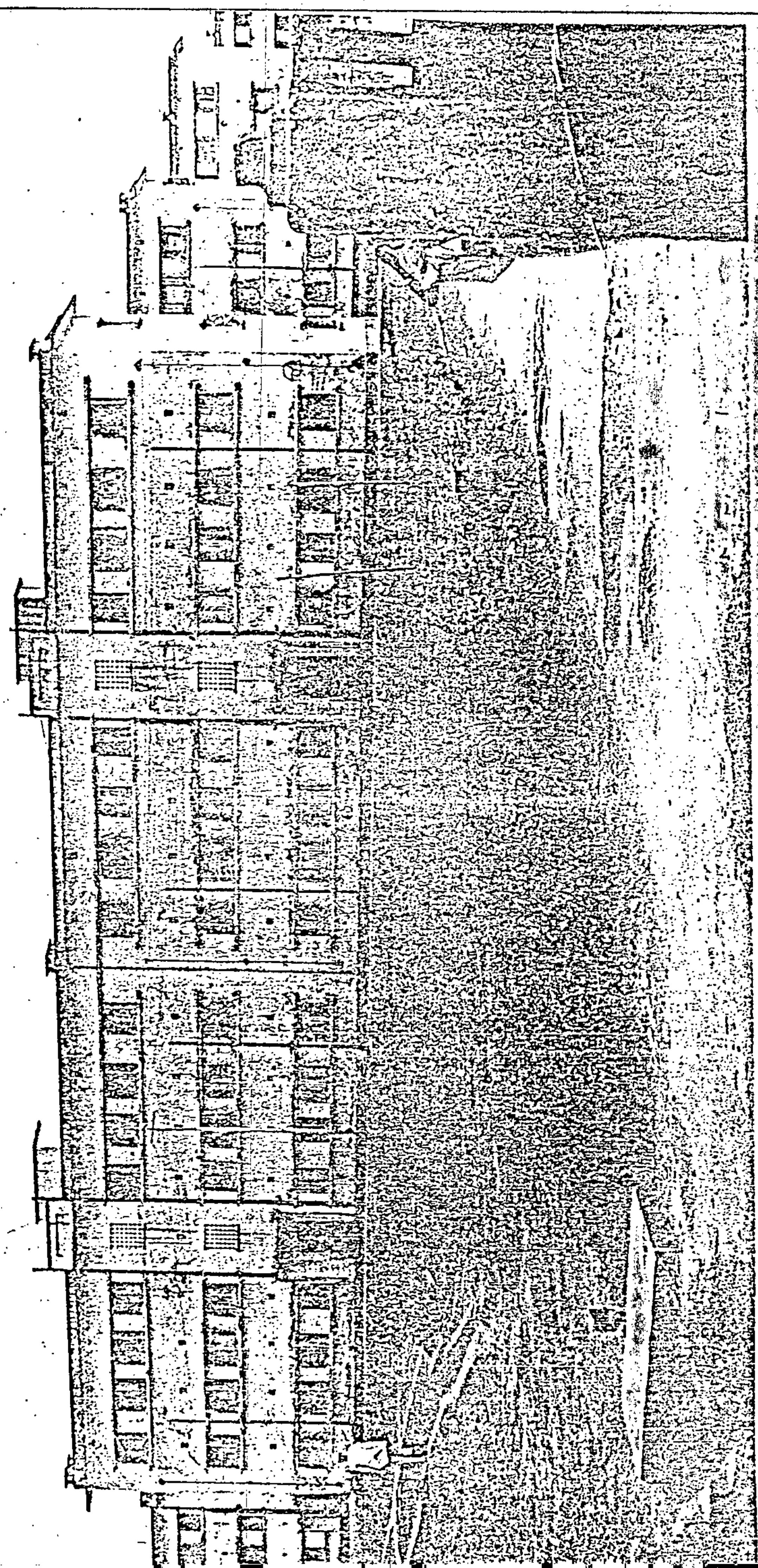
% DEWELLINGS USING TUBEWELL WATER

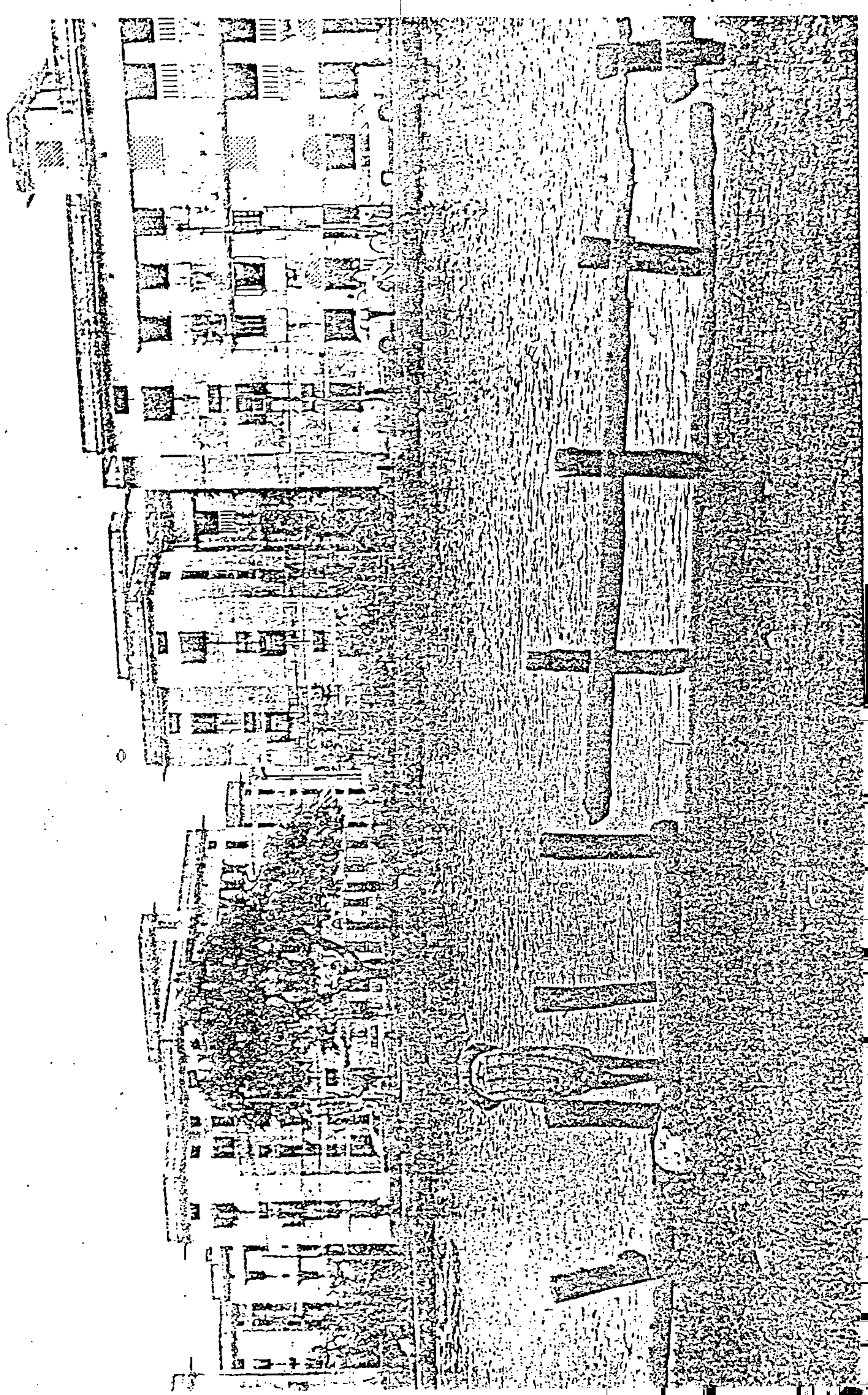

60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
PERCENTAGE OF MALE POPULATION
PERCENTAGE OF FEMALE POPULATION

NO	ELEMENT AND SUB ELEMENT	DESCRIPTION	NO OR M	EXP. LIFE IN YEARS	NO OF REPLACEMENTS	INITIAL COST	% OF TOTAL COST.	REPLACEMENT COST 1ST. 2ND. 3RD. ETC	COST OF GENERAL REPAIRS	TOTAL COST OF REPAIRS AND REPLACEMENTS	% OF ORIG. COST	REMARKS
	FOUNDATION	CONTINUOUS FOOTING	55 M LONG	60	NONE	2500 TK 112.5 ৳		NONE	NONE			
	WALLS	LOAD BEARING BRICK WALL	55 M LONG	60	NONE	3000 TK 150 ৳		NONE	NONE			IN CASE OF STRUCTURAL CRACK OR DAMAGE NEEDS REPAIR
	DOORS	WOODEN DOORS	7'-6" x 3'-4" 7'-6" x 2'-6" 10 NOS	20	2	1500 TK 75 ৳		1ST REPAIR 2500 TK 2ND REPAIR 3000 TK	1200 TK 60 ৳	6700 TK 335 ৳	—	—
	WINDOWS	WOODEN WINDOW	VARYING SIZES 11 NOS	20	2	1000 TK 50 ৳		1ST REPAIR 1667 TK 2ND REPAIR 2000 TK	1200 TK 60 ৳	4867 TK 244 ৳		
	FLOOR	R.C.C. FLOOR SLAB	$100 M^2$	60	NONE	1000 TK 50 ৳		NONE	500 TK 25 ৳	500 TK 25 ৳		
	ROOF	R.C.C. ROOF	$100 M^2$	60	NONE	3200 160 ৳		NONE	NONE			
		LIME CONC. SCREED	$100 M^2$	6	9	500 TK 25 ৳		600 x 9	NONE	5400 TK 270 ৳		DISTRIBUTED OVER 3 FLATS

NO	ELEMENT AND SUB ELEMENT	DESCRIPTION	NO OR M	EXP. LIFE IN YEARS	NO OF REPLACEMENTS	INITIAL COST	% OF TOTAL COST	REPLACEMENT COST 1ST. 2ND. 3RD. ETC	COST OF GENERAL REPAIRS	TOTAL COST OF REPAIRS AND REPLACEMENTS	% OF ORIG. COST	REMARKS
	PLUMBING	C.I. PIPE BRASS FIXTURES PORCELAIN PANS		30	1	1150 TK 6		1500 TK 75 £	750 TK 37·5 £	2250 TK 112·5 £		
	ELECTRICAL	15 AMP INSULATED COPPER WIRE		60	NONE	1500 TK 75 £		750 TK* 37·5 £	750 TK 37·5 £	1500 TK 75 £		* FOR OCCASSIONAL REPLACEMENT OF SWITCH ETC
	EXTERNAL FINISH	PLASTER SAND CEMENT	$300 M^2$	20	2	500 TK 25 £		1200 TK 60 £	200 TK 10 £	1400 TK 70 £		
		WHITE WASH	$300 M^2$	5	10	300 TK 15 £		400 X 10		4000 TK 200 £		
	INTERNAL FINISH	PLASTER SANDCEMENT	$300 M^2$	30	1	600 TK 30 £		800 TK 40 £	200 10 £	1000 TK 50 £		
		WHITE WASH WALLS AND CELING	$400 M^2$	10	5	400 TK 20 £		500 X 5		2500 125 £		
	STAIRS	R.C.C. STAIRS		60	NONE	750		NONE	750 TK	750 TK 37·5 £		


CEILING FAN
KITCHEN
BED ROOM 16'-6" x 12'-0"
6'-4" x 12'-0"
SITTING ROOM 12'-0" x 15'-0"
MULTIPURPOSE ROOM
9'-3" x 7'-6"
CEILING FAN
SHOWER
5'-9" x 4'-0"
TOILET
5'-9" x 2'-6"
ENTRY
ENTRY





APPENDIX 3

THERMAL INDICES

A. EFFECTIVE TEMPERATURE INDEX (E.T.)

The effective temperature index was developed by Houghten, Yaglou and Miller for the ASHRAE, The factors included are air temperature, humidity and air velocity. Two scales were developed for semi nude and for people clad in summer clothing. Two nomograms were developed for two kinds of clothing condition. It can be defined as the temp. of a still, saturated atmosphere, which would in absence of radiation produce the same effect as the atmosphere in question. It is found that if globe thermometer readings are used in the above mentioned nomograms, in lieu of the DBT values the subjective reactions to radiant heat are adequately allowed for. So in place of DBT, GT is used. This is known as corrected effective temperature scale or C.E.T. C.E.T. includes in addition to air temp. humidity and air velocity also the effect of radiation. C.E.T. index is still the most widely used scale.

B. EQUITORIAL COMFORT INDEX (E.C.I.)

Equitorial comfort index was developed by C.G.WEBB in Singapore in 1960. In Mr. Webb's language* "The nomogram combines the three factors, temp. humidity and air movement in to a single index of warmth called the Equitorial Comfort Index. The value of E.C.I. represents the subjective warmth of the climate; it tells you the way it feels to a fully acclimatised person

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*Webb, C.G. "Journal of the Institute of Heating and Ventilating Engineers" January 1960 vol. 27, P 297-304.

irrespective of whether the feeling is due to heat or humidity, or to the absence of cooling breezes." This is very similar to E.T.

C. RESULTANT TEMPERATURE (R.T.)

Resulyant temperature was developed by Missenard in France. This scale is a slight improvement over E.T. scale. Its development was motivated by an assumption that a firmer basis for a thermal index would be formed by experiments in which thermal equilibrium was achieved between body and environment; so that the effects of humidity and wind under these conditions could be found. It is not very effective for tropical conditions as it does not allow sufficiently for the cooling effects of air movement over 35 C and 80 percent r.h.

D. PREDICTED FOUR HOUR SWEAT RATE (P_4SR)

This scale attempts to correlate subjective sensation with climatic measurements. It is mainly concerned with the objective determination of physical stress as indicated by the rate of sweat secretion from the body, by the pulse and internal temp. Metabolic rates as well as clothing, air temperature, humidity, air movement and mean radiant temperature of the surroundings were considered. The experiments used as basis for the index were carried out over 4 —hour periods under different combination of climatic factors and work conditions. It was assumed that same sweat rate produced the same physiological stress. The scale is reliable for high temp. conditions. The cooling effect of air movements at humidities is underestimated

E. HEAT STRESS INDEX (H.S.I.)

The heat stress index was developed by Belding and Hatch, using theoritical calculations of the external heat stress acting on a man exposed to a given thermal environment, of the heat produced by metabolism for various degrees of activity, and of evaporative capacity of environment. The calculations are based on following assumptions.

a. Total heat stress acting on the body equals the requirement for sweat evaporations.

b. The physiological strain imposed on the body by a given heat stress is determined by the ratio of the required evaporative cooling to the maximum evaporative capacity of the air.

c. Constant skin temperature is maintained when the body is subjected to heat stress.

d. The maximum sweating capacity of an average person over an 8 hour period is approximately 1 l/hr. or a cooling value of 2400 BTU/hr.

e. All the latent heat of sweat evaporation is drawn from the body.

F. THE INDEX OF THERMAL STRESS (I.T.S.)

The index of thermal stress was developed by Givoni. Givoni describes it as "The index of thermal stress is based on the assumption that, within the range of conditions where it is possible to maintain thermal equilibrium, sweat is secreted at a sufficient rate to achieve the evaporative cooling required to balance the metabolic heat production and the heat exchange with the environment. The relation between sweat secretion and the required evaporative cooling depends on the cooling efficiency of sweating."*

The general formula

$$S = [(M-W) \pm C \pm R](1/f)$$

S = required sweat rate in equivalant Kcal/hr.

M = metabolic rate, Kcal/hr.

W = metabolic energy transformed in to mechanical work Kcal/hr.

C = convective heat exchange Kcal/hr.

R = radiant heat exchange Kcal/hr.

f = cooling efficiency of sweating, dimensionless.

*Givoni, B. "Man, Climate and Architecture" Elsevier publishing company limited 1969 P 68-95.

MATHEMATICAL FORMULA

A. Belding's formula for finding out MRT (47)

$$M.R.T. = t_g + 0{\cdot}24\, V^{0{\cdot}5}(t_g - t_a)$$

V = velocity of air in m/sec

t_g = Globe thermometer temp. in °C

t_a = air temp in °C

B. Belding's formula for finding maximum evaporative capacity (47)

for semi nude $E_{max} = 2{\cdot}0\, V^{0{\cdot}6}(42 - V_{pa})$

for light clothing $E_{max} = 1{\cdot}33\, V^{0{\cdot}6}(42 - V_{pa})$

V is air velocity in m/sec

Vpa is vapour pressure in mm Hg. Evaporative capacity in kcl/h/m.

C. Givoni's formula for sensible perspiration S.P. (15)

sensible perspiration $S.P. = (-0{\cdot}3 + 5(E/E_{max}))$

D. The volume of fresh air to keep CO_2 concentration below 0·2% when the volume produced per person is given by q (1/h)

$$Q = \frac{q \cdot 100}{(0{\cdot}2 - 0{\cdot}02) \cdot 1000} = \frac{q}{1{\cdot}8}$$

For sedentary activity when CO_2 production is 18 1/h $Q = \frac{18}{1{\cdot}8} = 10\ m^3/h$ per person.

When the person is doing manual work CO_2 is three times the normal production hence the requirement is $30\ m^3/h$ per person

E. In creating the stack effect the motive force is proportional to the vertical vertical distance h between the two openings, and the ratio $\Delta t/T$ where Δt is the indoor - outdoor temp. difference and T is the average absolute temp. ($°K = °C + 273$)

If the pressure head is given by ΔP

$$\Delta P = \frac{h \Delta t}{8{\cdot}5\, T} \; (cm\ H_2O)$$

Average weight of 1cm column of water is equal to 8·5 m of air at ordinary atmos. temp. & pressure.

The air flow Q induced by the thermal force can be found by the equation

$$Q = kA\,(h\Delta t)^{0.5}$$

K is a constant depending on the resistance of the openings. In metric system the value is 7 and the unit is $m^3/min/m^2$

F. Webb's heat and moisture balance equation is

Rate of heat lost by ventilation

= Sensible metabolic heat ± Wild heat

$$V\rho c p\, \Delta T = N(Q - e) \pm X$$

N = no of people X = wild heat

all other notations have usual meaning

$$\Delta T = \frac{Q - e}{\rho c p} \Big/ \frac{V}{N}$$

G. Van Straaten's formula

The air flow $Q_\omega = C_e \cdot A(K)\,V$

C_e = combined coefficient of discharge of flow through the openings

A = free area of inlet or outlet opening, assuming equal

K = dimensionless pressure ratio, pressure difference accross the building/free wind dynamic pressure

V = wind speed, ft. per min.

The value of C_e and hence Q_W is influenced by the distance between the inlet and outlets. When two openings are in series the air flow decreases as the distance between them increases. The rate of decrease is small after 12 ft. The dimensionless pressure ratio K is a measure of the effectivness of the building to convert the dynamic free wind pressure in to a static pressure difference accross the building. The numerical value is mainly affected by the direction in which wind is blowing relative to the building, layout or plan of the building, and structural features like roof pitch, overhang, wall height and wall length.

B. Givoni's (15) formula for average indoor velocity assuming inlet and outlet as equal.

$$\bar{V}_{(i)} = 0.45\,(1 - e^{-3.84\,X})\,V_{(o)}$$

$\bar{V}_{(i)}$ = average indoor velocity

X = ratio of window areas to the wall

$V_{(o)}$ = outdoor wind speed

APPENDIX 5

Location	DACCA, BANGLADESH
Longitude	90·6 E OF GR
Latitude	24° N
Altitude	7 M 23 FT.

Air temperature: °C

	J	F	M	A	M	J	J	A	S	O	N	D	High	AMT
Monthly mean max.	25·1	27·6	32·1	33·9	32·8	31·8	31·0	31·0	31·5	31·2	28·3	26·4	33°C	23·5
Monthly mean min.	13·0	15·0	20·0	23·4	24·4	25·6	26·0	26·0	26·0	24·0	16·9	14·2	13°C	20·6
Monthly mean range	12·1	12·6	12·1	10·2	8·4	6·2	5·0	5·0	5·5	7·2	11·4	12·2	Low	AMR

Relative humidity: %

	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max. a.m.	80	76	76	78	79	86	87	87	84	80	78	82
Monthly mean min. p.m.	53	50	45	52	73	78	79	78	78	73	66	64
Average	66·5	63	60·5	65	76	82	83	82·5	81	76·5	72	73
Humidity group	3	3	3	3	4	4	4	4	4	4	4	4

Humidity group:	1	If average RH: below 30%
	2	30–50%
	3	50–70%
	4	above 70%

Rain and wind

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Rainfall, mm	8·32	31·5	58·7	137·1	224·9	314·7	328·4	324·8	247·9	123·9	20·3	5·1	1847

	J	F	M	A	M	J	J	A	S	O	N	D
Wind, prevailing	N	N	S	S	S	S	S	S	S	S	N	N
Wind, secondary		S		NW						N		

Comfort limits		AMT over 20°C		AMT 15–20°C		AMT below 15°C	
		Day	Night	Day	Night	Day	Night
Humidity group:	1	26–34	17–25	23–32	14–23	21–30	12–21
	2	25–31	17–24	22–30	14–22	20–27	12–20
	3	23–29	17–23	21–28	14–21	19–26	12–19
	4	22–27	17–21	20–25	14–20	18–24	12–18

TABLE 2
Diagnosis: °C

	J	F	M	A	M	J	J	A	S	O	N	D	
Monthly mean max	25·1	27·6	32·1	33·6	32·8	31·8	31·0	31·0	31·5	31·2	28·3	26·4	23·3 AMT
Day comfort: upper	29	29	29	29	27	27	27	27	27	27	27	27	
lower	23	23	23	23	22	22	22	22	22	22	22	22	
Monthly mean min.	13·0	15·0	20·0	23·4	24·4	25·6	26·0	26·0	26·0	24·0	16·9	14·2	
Night comfort: upper	23	23	23	23	21	21	21	21	21	21	21	21	
lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress: day	–	–	H	H	H	H	H	H	H	H	H	–	
night	C	C	–	H	H	H	H	H	H	H	–	C	

Indicators

		J	F	M	A	M	J	J	A	S	O	N	D	Totals
Humid:	H1			✓	✓	✓	✓	✓	✓	✓	✓	✓		9
	H2													
	H3					✓	✓	✓	✓	✓				5
Arid:	A1													0
	A2													0
	A3													0

Meaning	Indicator	Applicable when: Thermal stress Day	Night	Rainfall	Humidity group	Monthly mean range
Air movement essential	H1	H			4	
		H			2, 3	Less than 10°
Air movement desirable	H2	O			4	
Rain protection necessary	H3			Over 200 mm		
Thermal capacity necessary	A1				1, 2, 3	More than 10°
Out-door sleeping desirable	A2		H		1, 2	
		H	O		1, 2	More than 10°
Protection from cold	A3	C				

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
9		5			

Layout

H1	H2	H3	A1	A2	A3		No.	Recommendation
			0–10 ✓			✓	1	Orientation north and south (long axis east–west)
			11, 12		5–12			
					0–4		2	Compact courtyard planning

Spacing

H1	H2	H3	A1	A2	A3		No.	Recommendation
11, 12							3	Open spacing for breeze penetration
2–10 ✓						✓	4	As 3, but protection from hot and cold wind
0, 1							5	Compact lay-out of estates

Air movement

H1	H2	H3	A1	A2	A3		No.	Recommendation
3–12 ✓						✓	6	Rooms single banked, permanent provision for air movement
1, 2			0–5 ✓					
1, 2			6–12				7	Double banked rooms, temporary provision for air movement
0	2–12							
0	0, 1						8	No air movement requirement

Openings

H1	H2	H3	A1	A2	A3		No.	Recommendation
			0, 1 ✓		0 ✓	✓	9	Large openings, 40–80%
			11, 12		0, 1		10	Very small openings, 10–20%
Any other conditions							11	Medium openings, 20–40%

Walls

H1	H2	H3	A1	A2	A3		No.	Recommendation
			0–2 ✓			✓	12	Light walls, short time-lag
			3–12				13	Heavy external and internal walls

Roofs

H1	H2	H3	A1	A2	A3		No.	Recommendation
			0–5 ✓			✓	14	Light, insulated roofs
			6–12				15	Heavy roofs, over 8 h time-lag

Out-door sleeping

H1	H2	H3	A1	A2	A3		No.	Recommendation
				2–12			16	Space for out-door sleeping required

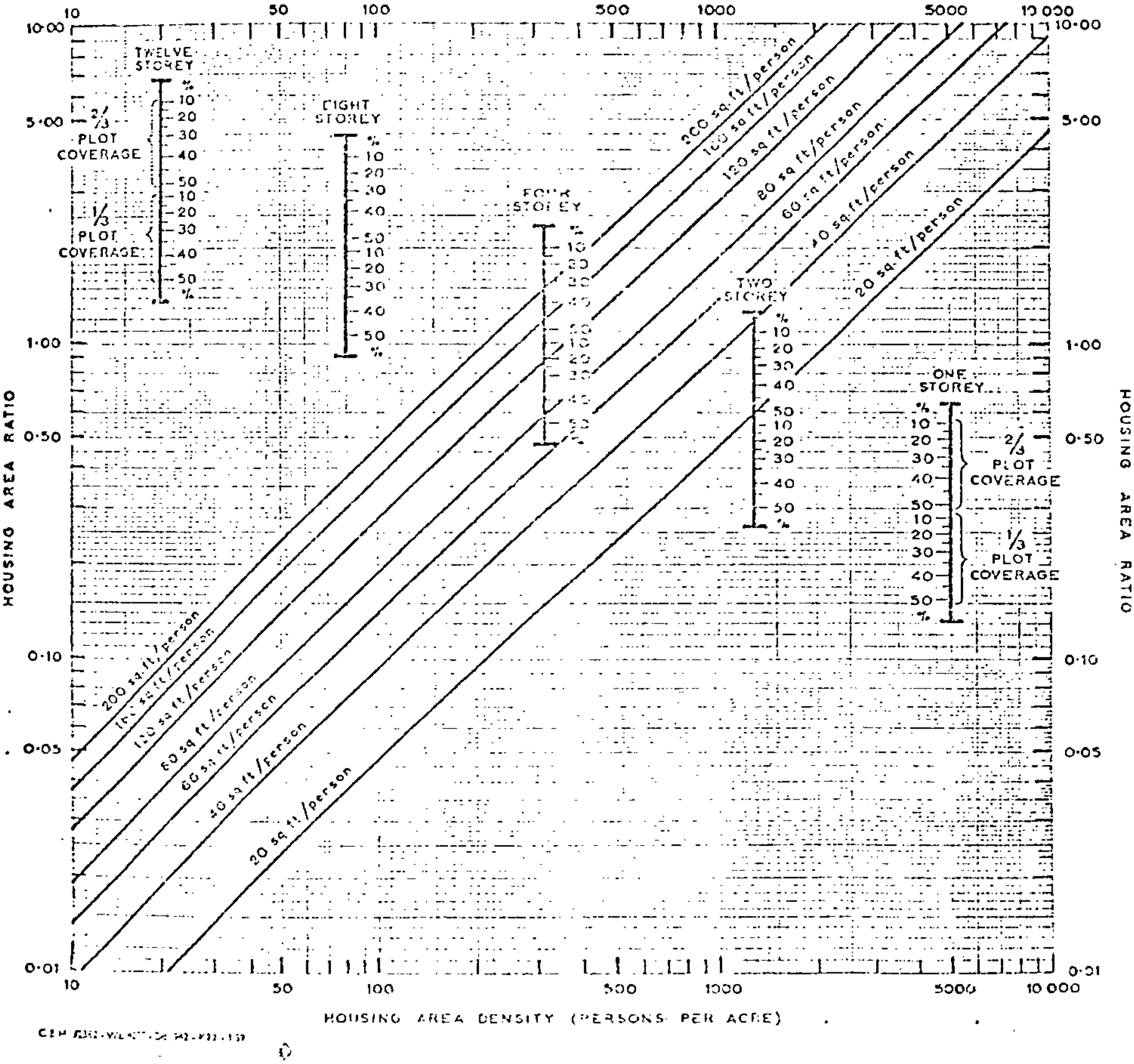
Rain protection

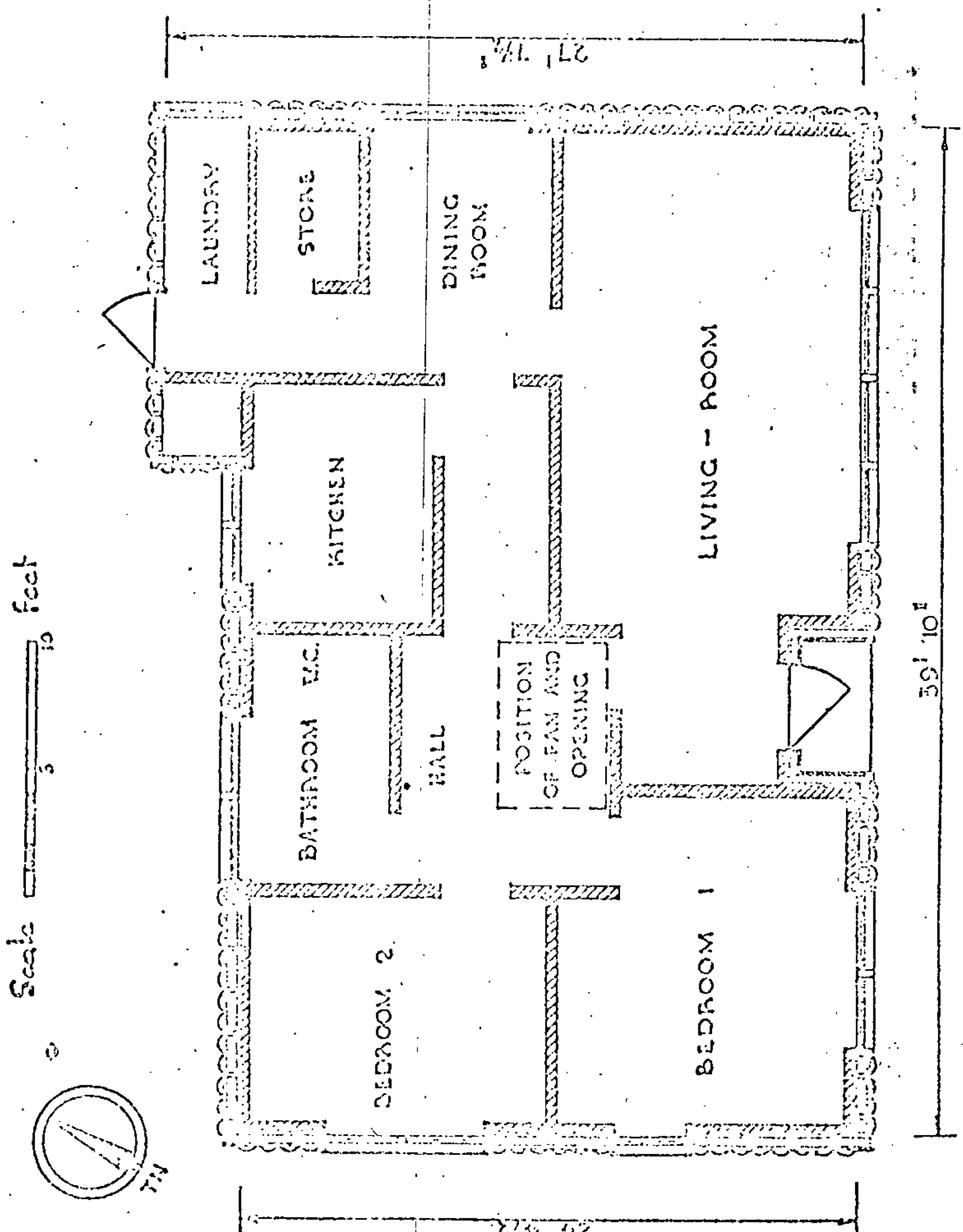
H1	H2	H3	A1	A2	A3		No.	Recommendation
		[illegible]2 ✓				✓	17	Protection from heavy rain necessary

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
9		5			

H1	H2	H3	A1	A2	A3	✓	No.	
								Size of opening
			0, 1 ✓		0	✓	1	Large: 40–80%
			0, 1		1–12		2	Medium: 25–40%
			2–5				2	Medium: 25–40%
			6–10				3	Small: 15–25%
			11, 12		0–3		4	Very small: 10–20%
			11, 12		4–12		5	Medium: 25–40%
								Position of openings
3–12 ✓						✓	6	In north and south walls at body height on windward side
1–2			0–5 ✓			✓	6	In north and south walls at body height on windward side
1–2			6–12				7	As above, openings also in internal walls
0	2–12						7	As above, openings also in internal walls
								Protection of openings
					0–2 ✓	✓	8	Exclude direct sunlight
		2–12 ✓				✓	9	Provide protection from rain
								Walls and floors
			0–2 ✓			✓	10	Light, low thermal capacity
			3–12				11	Heavy, over 8 h time-lag
								Roofs
10–12			0–2 ✓				12	Light, reflective surface, cavity
10–12			3–12			✓	13	Light, well insulated
0–9 ✓			0–5 ✓			✓	13	Light, well insulated
0–9			6–12				14	Heavy, over 8 h time-lag
								External features
				1–12			15	Space for out-door sleeping
		1–12 ✓				✓	16	Adequate rainwater drainage

FIG. 2. HOUSING AREA RATIO, DENSITY AND PLOT COVERAGE.





Floor plan of the house used in E.T. WESTON'S (53) experiment.

APPENDIX 4

RATES OF CHANGE OF THE AIR VOLUME OF INDIVIDUAL ROOMS AND [illegible]

ROOM OR COMBINATION OF ROOMS	VOLUME, cu. ft.	RATES OF CHANGE OF THE AIR VOLUME OF ROOMS FOR ALL UNDERMENTIONED RATES OF CHANGE OF THE AIR VOLUME OF THE HOUSE				
		38	43	60	70	80
Living-room.	2,310 (incl. entrance)	143	162	228	265	304
No. 1 bedroom.	1,320	250	284	400	463	533
No. 2 bedroom.	900	368	417	585	679	781
Living-room and No. 1 bedroom.	3,630	91	103	145	168	194
Living-room and No. 2 bedroom.	3,210	103	117	164	190	219
Living-room and Nos. 1 and 2 bedrooms.	4,530	73	83	118	135	155
Nos. 1 and 2 bedrooms.	2,220	149	169	237	275	316
Kitchen.	644	514	582	818	950	1,092
Dining room.	578	572	648	910	1,058	1,216
Kitchen and dinette.	1,222	271	307	431	500	575
Living-room and kitchen.	2,954	112	127	178	207	238

Table from E.T. WESTON'S experiment, data on air changes.

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