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AN ANALYTICAL STUDY OF SUN-BUILDING INTERACTION

(With reference to Dhaka : 23°45'N & 90°15'E)

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree of

MASTER OF ARCHITECTURE

By

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CERTIFICATE

Certified that the dissertation entitled,' AN ANALYTICAL STUDY OF SUN-BUILDING INTERACTION (with reference to Dhaka: 23°45'N and 90°15'E)', which is being submitted by Qazi Azizul Mowla in partial fulfillment for the award of degree of MASTER OF ARCHITECTURE of the University of Roorkee, is a record of his work carried out by him under my supervision and guidence. The matter embodied in this dissertation has not been submitted for any other degree or diploma.

This is to further certify that he has worked for a period of six months, from July'84 to January'85, for the preparation of this dissertation at this University.

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ABSTRACT

It is a common knowledge that whereas the fabric of a building last for about a hundred year, the system for thermal controls within buildings last for a much shorter period and hence due emphasis should be put on envelope of the building for economical thermal designs.

Various approaches adopted for 'Built environments' are invariably based on past experience or rules of thumb and in quite a few situations mistakes are committed. It is therefore necessary to evolve a rational system for the guidance of designers.

The effect of sun on the building, which is one of the major environmental factors for thermal design is, therefore, studied analytically for Dhaka, in this dissertation. Graphs are developed to enable an Architect to select suitable and optimum, orientations of building and openings, height and width of openings, type and size of shading devices, depth of staggering and cantilever, suitable arrangement of spaces, selection of materials, colour etc.,etc. as demanded by 'Sun' as a factor in the total built-environment.

Published data, protractors, formulae etc. developed by building scientists are freely used to achieve the target, but the approach is primarily based on solar geometry and its radiation. It is believed that the final decision should be the designers and that this investigated approach (which can be developed for any location in a similar way), will surely make the decisions easy and more scientific.

1.0 INTRODUCTION

1.1 Introductory Remark

The earth is a member of solar system, of which the sun is the binding force. Architecture is the product that takes its shape with the sun, the earth and the sky are the true material out of which the architecture is made.

Although there is a definite mathematical relationship between the sun and the form performance yet designers have continued intuitive and conventional approaches with respect to climatic design of building. It may be due to the fact that the results of research and developments are not available in such consolidated form or so complex to be easily applied in the design while very many parameters at the planning stage are under consideration.

1.2 Scope of Study

Concious incorporation of environmental facts in the design is beyond controversy but the strategic decisions about building form, construction and its performance should be at conceptual and system levels. An understanding of natural laws will aid in developing a building that responds properly to environmental conditions maintaining interior comfort with minimum efforts .

Indoor thermal conditions, upto a certain extent can be improved by judicious selection of building components, materials, optimum orientation and proper selection of shading devices. The main aspect of the design of thermally comfortable buildings are minimising the flow of solar heat and reducing wall and roof surface temperature under summer condition in Dhaka.

An experienced designer may possible know in eneral terms as to what extent, the building will respond to sun but exact delineation of performance would require mathematical calculations.

1.3 Objectives of Study

In the dissertation, rather than blindly following the codes of practice, a limited attampt is sought to apply the laws of nature and physical sciences, as the technology of contemporary research in physical sciences has introduced a scale of design, which is beyond usual architecture, one, that poses special problems as to the location, behaviour and utility. The study is in particular for Dhaka (Bangladesh) to see the effect of sun on the buildings.

The purpose of the study is not to see the workability of the existing architecture in Dhaka, but to carry out an analytical study on one of the environmental aspects, i.e. sun-building interaction, that effects and influences the indoor comfort conditions and than to recommend a design guide line with emphasis on ' sun ' . The other general guide lines for warm humid regions covering all aspects, will be assumed to hold good for Dhaka.

The enumeration of the desired form performance relationship would be analysed as follows:

- Duration of solar radiation received on the surface -vs - variation in the angle of orientation of facade.
- Intensity of solar radiation received on the surface -vs - variation in the angle of orientation of the facade.
- Degree of exposure of a facade to solar irradation -vs - variation in the spacing between successive parallel rows and variations in the depth of staggering between two adjacent and parallel strip of same facade and its angle of orientation.

Extent of solar heat infiltration through the envelope-vs- variation in the U-value of the envelope and solar radiation absorptivity and surface conductance of the outside surface of the envelope.

Effect on the decrement factor and time-lag produced by the envelope -vs- variation in the thickness of the envelope, the nature of its construction and its density.

In short, to evolve quick and easy graphical methods and simple calculations for the assessment of natural sun-building interactions with referencee to Dhaka is the objectives of this study.

2.0 DEFINING THE TERMS: THE SUN AND THE BUILDING

In order to analyse the effect of sun on buildings, it is essential to know the basic characteristics and extent of influence of interacting aspects. Two basic terms comprising the title of dissertation e.g. The Sun and The Building' is therefore, studied here as a basic background work to arrive at certain assumptions and to show the exact direction of study.

2.1 The Sun

2.1.1 Sun-Earth relationship:

The earth is a member of solar system, of which the sun is the binding force. The earth moves round the sun in 23°27' tilting position from its vertical axis. It performs three types of movements simultanously i.e. rotation, revolution and the travel with the whole solar system family towards constellation Hercules at a speed of 19.3 km/sec to an unknown destination.

Rotation is the movement of earth round its own axis which is 23°27' tilted from the vertical axis and the revolution is the movement of earth round the sun. Because of the regularity of the earth's rotation and revolution, it gives rise to days and nights and different seasons and also the daily and seasonal pattern of weather and climate. Climate is affected by latitude, time of a day and time in a year and also due to its tilt. Integrated results of tilted rotation and revolution are length of days, nights and seasons and all the basic climatic elements(29).

2.1.2 Solar Radiation

Solar radiation is an electromagnetic radiation emitted from sun. The solar spectrum is broadly divided into three regions i.e. the ultra-violet(below 0.4 microns), the visible (0.4 - 0.76 micron) and the infra-red(0.76 - above).

Although the peak intensity of solar radiation is in the visible range, over-half of the energy is emitted as infra-red radiation.

Solar energy at the upper limits of atmosphere varies from 158 to 175 watt/m^2(1.8 to 2.0 cal/cm^2/min) according to the earth distance from the sun and the solar activity. On average it is 170 watt/m^2(1.97 Cal/cm^2/min) and is known as solar constant'. As the radiation penetrate the earth's atmosphere, its intensity is decreased and the spectral distribution is altered by absorption, reflection and scattering(25).

Radiation is selectively absorbed in the atmosphere. Most of the ultra-violet and all wave length below 0.288 micron are absorbed by water vapour and carbon di-oxide. Reflections takes place mainly from water droplets and is effectively non selective. When impinging on moledules and particles of dimensions similar to or smaller then wave length, radiation is reflected and diffused in space. This is a selective phenonenor and the amount of scaltered radiation of each wave length is proportional to the fourth power of the reciprocal of the wave length. However, the amount of solar energy actually reaching the earth depends also on the sky clearance with respect to cloud, and the purity of the air with respect to dust, carbon-di-oxide and water vapour; these are the factors which have to be estimated rather the calculated(Fig.1).

2.1.3 Long wave radiative heat loss:

Long wave is emitted by the surface of earth to the atmosphere in a higher wave length in heat form at low temperature. The gasses comprising the atmosphere absorbs and emits radient energy, not as a black body but in a selective way, while only a small part of short-wave solar

		%
a = reflected from the gr.		5
b = reflected from cloud		20
c = absorbed in atmpr.		25
d = defused in the ground		23
e = direct on the ground		27
	total on the ground	50

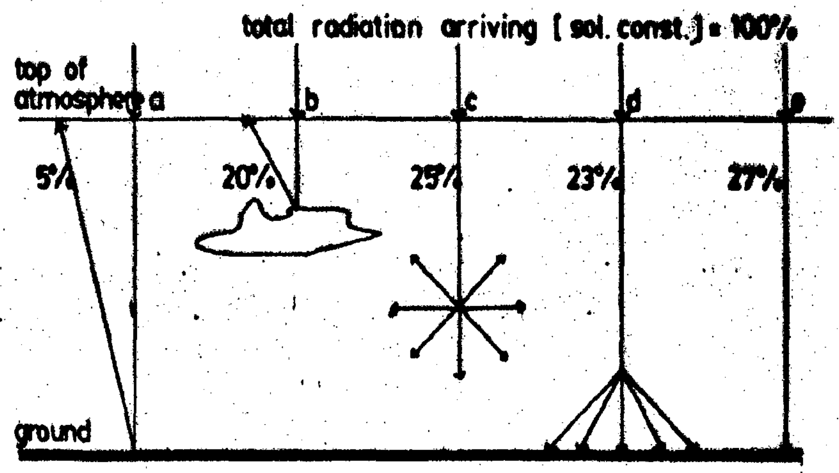


FIG: 1 Passage of Radiation through the atmosphere (29)

top of atmosphere

a = long wave radiation		20
b = evaporation		20
c = convection		10
	total	50

ground

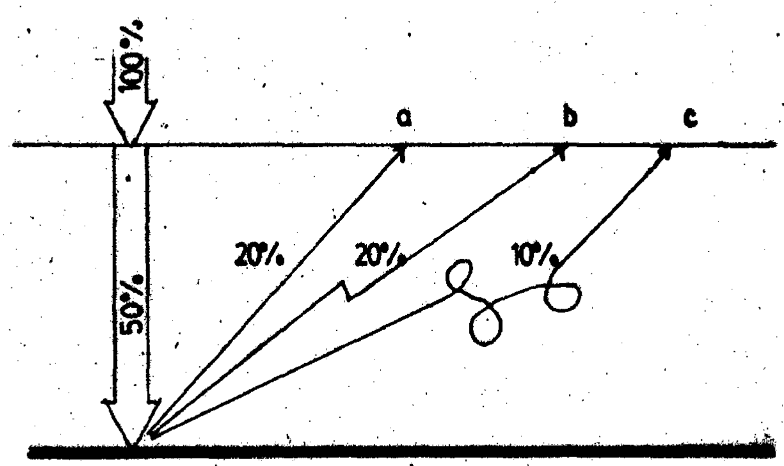


FIG: 2 Heat Release from ground and atmosphere (29)

$\cos \beta = \frac{B}{C}$

area C > area B

intensity C < intensity B

$I_C = I_B \times \cos\beta$

∴ Solar radiation normal to surface is maximum

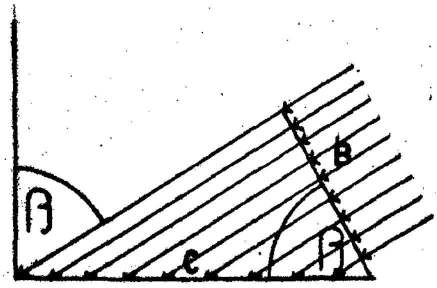


FIG: 3 The Angle of incidence (29)

Note :-

- at lower latitudes radiation is more
- less the sun's altitude, lesser is its intensity

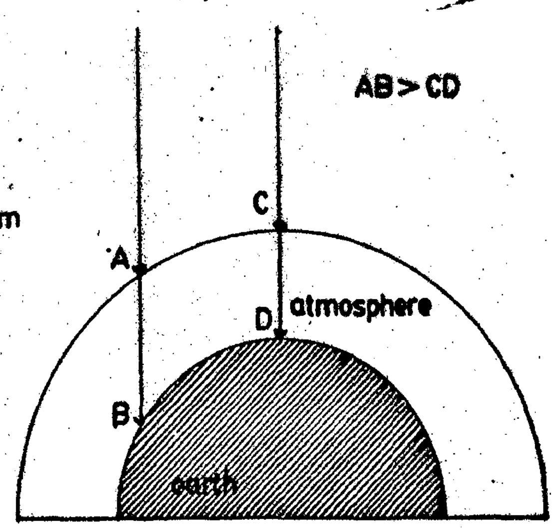


FIG: 4 Length of path through the atmosphere (29) radiation is removed, most out going long wave radiation is absorbed in the air. However, only certain wave lengths are effected and the remaining continues to travel into space(29) Fig.2. The phenomena is called sky window:

Heat released by the object in the roof at low temperature is absorbed by CO_2 and H_2O present in the air, irrespective of the source from where it is comming i.e. directly from the sun or reflected from the ground.

The difference between the amount of radiation discharged from the earth's surface and emited back to earth by the atmosphere is the net radiative heat loss. The intensity of emited radiation is proportional to the difference between the fourth powers of the absolute temperature of emiting and absorbing points i.e. $T_E^4 - T_A^4$.

The radiative heat loss is therefore, highest when the atmosphere is clear and dry. Net radiative heat loss from a given surface R' by Geiger(24) is

$$R = 8.26 \times 10^{-11} \times T^4(0.23 + 0.28 \times 10^{-0.074P}) \qquad 01.$$

where T = absolute temperature

P = water vapour pressure in atmosphere in mm Hg.

The formula applies to cloudless sky. The effect of water vapour pressure on the long wave radiation heat loss 'R' for surface temperature of 10°, 20° and 30° are as follows.

Table:01 Net long wave heat flow (cal/cm²/min)

Temperature	Vapour pressure, mm. Hg.						
	4	6	8	10	15	20	30
10°C	0.197	0.175	0.160				
20°C	0.225	0.20	0.183	0.160	0.153		
30°C	0.26	0.23	0.21	0.195	0.163	0.155	0.150

Note: multiply by 87.8 to convert into watt/m², Geiger(24) remarks that the values obtained from the above formula may be too high, by about 17 %. When the sky is clouded the outgoing radiation is reduced (but even cloudy days provide upto 1/3 of useful radiation that is available on a cloudless day at the same time of the year). Geiger cites the following results of measurement of out going radiation, as percentages of the values for cloudless sky.

Table: 02

Cloudiness in tenths	0	1	2	3	4	5	6	7	8	9	10
% Outgoing radiation	100	98	95	90	85	79	73	64	52	35	15

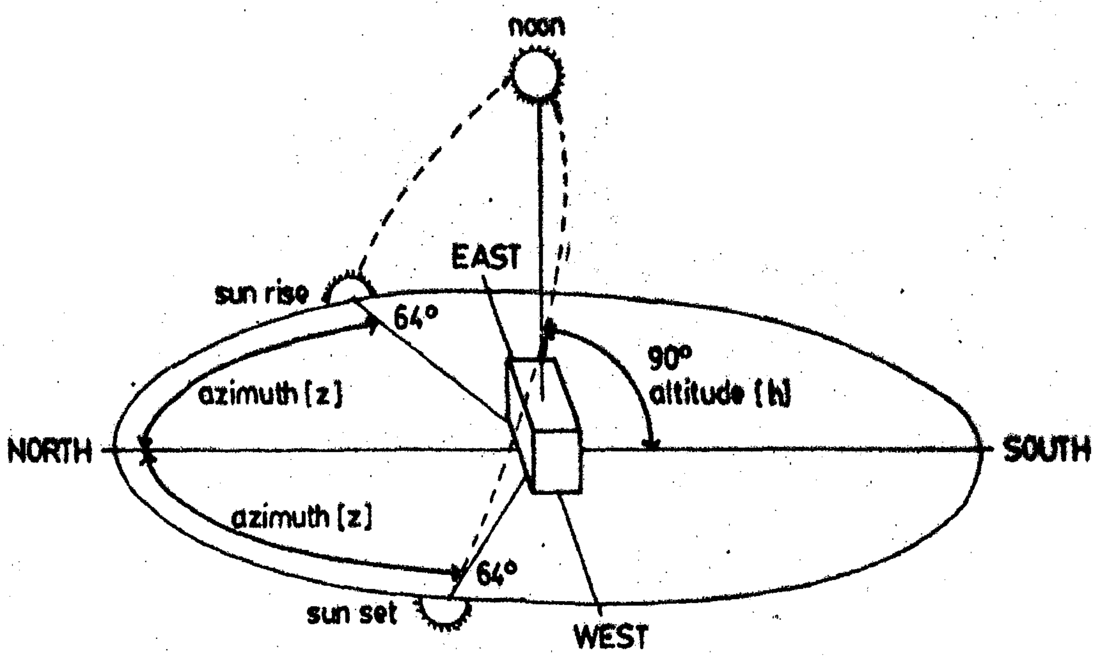
2.1.4 Radiation at earth's surface:

The earth-sun relationship affect the amount of radiation received at a particular point on the Earth's surface in three ways:

- Cosine law(29): which states that the intensity of radiation on tilted surface equals the normal intensity times the cosine of angle of incidence, and hence loss radiation(Fig. 3).
- Atmospheric depletion(24): i.e. the absorption of radiation by ozone, vapours and dust particles in the atmosphere. The lower the solar altitude angle, the larger the path of radiation through the atmosphere, thus a smaller part reaches the earth's surface.(Fig. 4).
- Duration of sunshine i.e. the length of day light period(29).

2.1.5 Assessment of Solar Radiation on earth surface

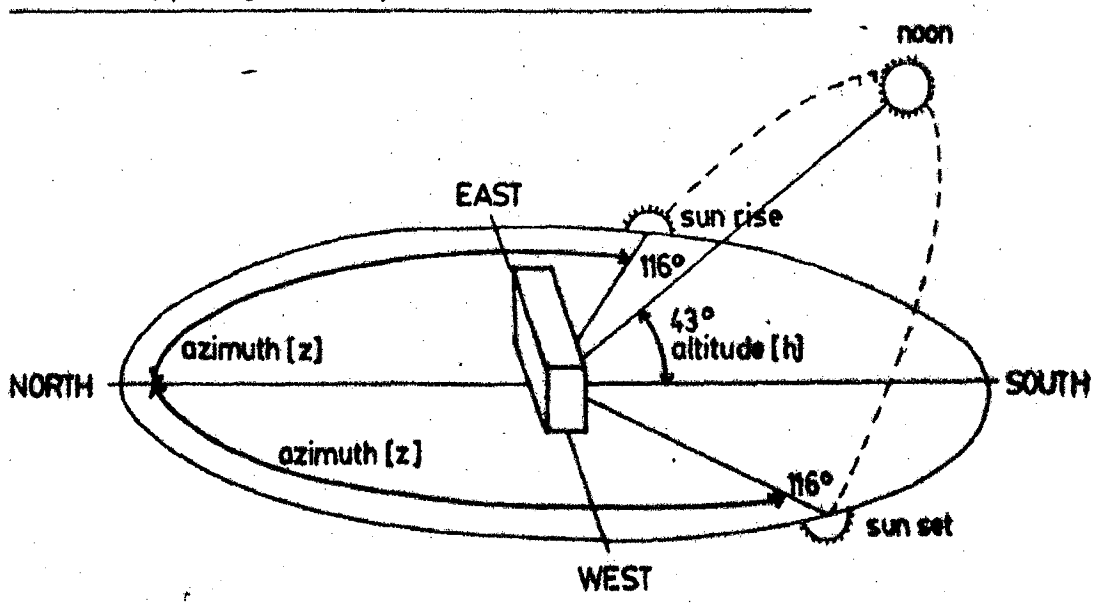
The sun's radiation is received in three ways i.e.



summer [june 22] sun path

Findings :

- In summer, southern facade does not get any sun throughout the day but northern facade gets low altitude morning and evening sun.
- In winter, southern facade gets the sun throughout the day, since sun altitude is low, it penetrates deep into the building.
- East and west facade gets beforenoon and afternoon sun respectively, throughout the year.



winter [dec. 22] sun path

FIG:5 . Sun Angles for Dhaka [23°45' north latitude(I)] author

- Direct(I_D): Light that casts a shadow direct from the sun.
- Diffused(I_d): Non-shadow-casting light from the whole sky vault.
- Reflected(I_r): Direct or diffused radiation that bounces off objects.

Three component comprises the total solar radiation (I) on building envelope:

$$I = I_D + I_d + I_r \qquad 02.$$

For most of the problems delt with in this context the position of the sun must be known at any time. This position is defined by the height of the sun above the - horizon (solar altitude:h) and its bearing with respect to the earth (solar azimuth Z) the diurnal and annual pattern of these two characteristics depends on the geographical latitude(l) Fig.5 ,the solar altitude(h) and azimuth(Z) with respect to the south can be calculated by the formulae(25).

$$\text{Sin } h = \sin l. \sin d + \cos l. \cos d. \cos(15T) \qquad 03.$$

and

$$\text{Sin } Z = \frac{\sin(15T). \cos d}{\cos h} \qquad 04.$$

where, T = The time interval between the given hour and the solar noon, in absolute units.

l = Geographical latitude

d = Solar declination

Again, sun rise azimuth(SRA) and sun rise time(SRT) can be calculated as follows

$$SRA = \text{arc} \cos(\cos l.\sin d + \tan l.\tan d.\sin l.\cos d) \qquad 05.$$

$$SRT = 12 - \frac{\text{arc} \cos(- \tan l. \tan d)}{15} \qquad 06.$$

$\therefore$ Sun set time = 24 - SRT.

$$d = 23.45[\tfrac{360}{365}(NDY + 284)] \qquad 07.$$

where NDY = Number of day in year.

Calculation of the radiation: The amount of direct radiation falling on a surface is equal to the direct normal (I_{DN}) radiation corrected for the angle of incidence(θ) of the surface(25)

$$I_D = I_{DN} \cos\theta \qquad 08.$$

But $$I_{DN} = I^{O} \exp(-a/\sin h) \qquad 09.$$

where a = extinction co-efficient as suggested by Stephenson.

I^{O} = apparent solar constant and 'exp' refers to the base of the natural logarithm raised to the given power.

When the intensity of direct normal radiation is known, the component of this radiation empinging on a surface with any orientation can be found out. The intensity of direct radiation on horizontal surface (I_{DH}) is given by

$$I_{DH} = I_{DN} \sin h \qquad 10.$$

Again, the direct radiation on a vertical wall (I_{DV}) depends on the angle of incidence of the solar beam on the wall, these are calculated by:

$$I_{DV} = I_{DN} . \cos\theta \qquad 11.$$

Therefore, for a vertical plane the angle of incidence is computed as a function of sun's altitude angle(h) and its bearing angle relative to the wall(α).

$$\cos\theta = \cos h . \cos \alpha . \qquad 12.$$

The diffused and reflected radiation shoud be added to the direct component to obtain the total solar radiation incident on the wall. The relative quantity of diffused radiation(I_d) increases as the altitude(h) of the sun is reduced, cloud and atmospheres dust upto a certain degree increases this component.

$$I_d = K \, I_{DV} \qquad 13.$$

The value of 'K' varies for clear sky it is about 0.14 and for bright overcast sky, it is 0.9. To make a practical approximate estimation, the diffused radiation on any wall may be taken as one-half of the total diffused radiation. Sharma and Pal(50) calculated the ratio between that total(I_{TH}) and diffused radiation on a horizontal surface, and expressed this ratio as a function of the clearance number (C.N) of the atmosphere.

Table: 03

Sky	C.N.	Diffused/Total Radiation
Clear	1.0	12
Clear, slightly hazy	0.8	25
Hazy	0.6	35
Over cast	0.4	55

The reflected radiation (I_r) from the ground and surrounding surfaces depends on their reflectivety or albedo:

$$I_r = \frac{1}{2} \gamma I_{TH} \quad \text{where } \gamma = \text{albedo} = 0.2 \qquad 14.$$

hence, Ground reflected radiation (I_{GRV}) on vertical surface is:

$$I_{GRV} = \gamma I_{TH} = \gamma (I_{DH} + I_{dh}) \qquad 15.$$

From these basic relationships more information can be computed as follows:

Direct radiation on sloping surface(I_{DS}).

$$I_{DS} = I_{DN} \sin h \sin \phi + I_{DN} \cos h \cos \alpha \cos \phi \qquad 16.$$

where α = wall solar azimuth

ϕ = angle of inclination of sloping surface to the vertical.

Total radiation on horizontal surface (I_{TH}):

$$I_{TH} = I_{DH} + I_{dH} = I_{DN} \sin h + I_{dH} \qquad 17.$$

- Total radiation on vertical surface (I_{TV}):

$$I_{TV} = I_{DV} + I_{dV} + I_{GRV} = I_{DH}\cos h.\ \cos + \frac{1}{2} I_{dh} + I_{GRV} \quad 18.$$

- Total radiation on sloping surface(I_{TS}):

$$I_{TS} = I_{DH}\sinh.\sin\phi + \cosh.\cos\alpha.\cos\phi + I_{dh}\left(\frac{1+\sin\phi}{2}\right) \quad 19.$$

2.1.6 Effect of surface orientation on Intensity of Incident Solar Radiation

To estimate the intensity of solar radiation incident on surfaces in different orientations, there is a simplified procedure using data on the normal radiation intensity. Although the reflected radiation is neglected and the determination of diffused radiation inaccurate, this method enables rapid assessment of the effect of orientation on solar radiation exposure, particularly on clear days when the level of diffused radiation is low. The procedure was employed by Ashbel to evaluate for each month, the daily Irradiation pattern of horizontal and vertical surfaces at different orientations and at any geographical latitude.

The equations used by Ashbel to find the radiation (I) on a wall took into account the normal radiation(I_N). The solar altitude(h), azimuth(Z), declination(d), hour angle(t) measured from the south and latitude(l), the equations for the various orientations which apply only to the northern hemisphere are:-

$$I_{south} = I_N \cos h \cos Z = I_N(\cos d.\sin l.\cos t - \sin d.\cos l) \quad 20$$

$$I_{north} = - I_N \cos h \cos Z \quad 21$$

$$I_{east} = I_N \cos h \sin Z = I_N \cos d.\ \sin t. \quad 22$$

$$I_{west} = - I_N \cos h \sin Z \quad 23$$

$$I_{SE} = I_N \cos h(\cos Z + \sin Z)\cos 45^\circ \quad 24$$

$$I_{SW} = I_N \cos h(\cos Z - \sin Z)\cos 45^\circ \quad 25$$

$$I_{NE} = I_N \cos h(\sin Z - \cos Z)\cos 45^0 \qquad 26$$

$$I_{NW} = - I_N \cos h(\cos Z - \sin Z) \cos 45^0 \qquad 27$$

2.1.7 Solar radiation and sunshine hours

It may be noted, however, that if there are no radiation data available, but the duration of sun-shine is recorded, one can estimate the daily total radiation, using the expression given by Glover and McCulloch(26):

$$Q = Q_{sc}(0.29 \times \cos \phi + 0.52 \frac{n}{N}) \qquad 28$$

Where Q = daily total radiation on horizontal plane(Wh/m^2 day)

Q_{sc} = solar constant per day 9850 Wh/m^2 day.

ϕ = Geographical latitude.

N = possible sun shine hours per day

n = actual sun shine hours per day

Omotto suggested the use of 0.26 and 0.51 respectively as constants for latitude and sunshine hours.

2.2 The Building

2.2.1 Natural forms:

A natural built form is sympathetic to its surroundings and in its orientation, taking advantage of southfacing windows in northern latitudes to acquire solar heat in winter, while avoiding the low-level radiation from the east and west in summer, which would create intolerable conditions without airconditioning. The building conserves its internal, unnatural climate, without rejecting the more useful components of the natural, external climate. Traditionally, the buildings employ five basic passive systems to ensure internal comfort i.e. (a) Convective pool (b) Roof pond (c) Direct gain (d) Thermal storage wall (e) Solar green house(Fig. 6).

In nature the plant life shows a close relationship

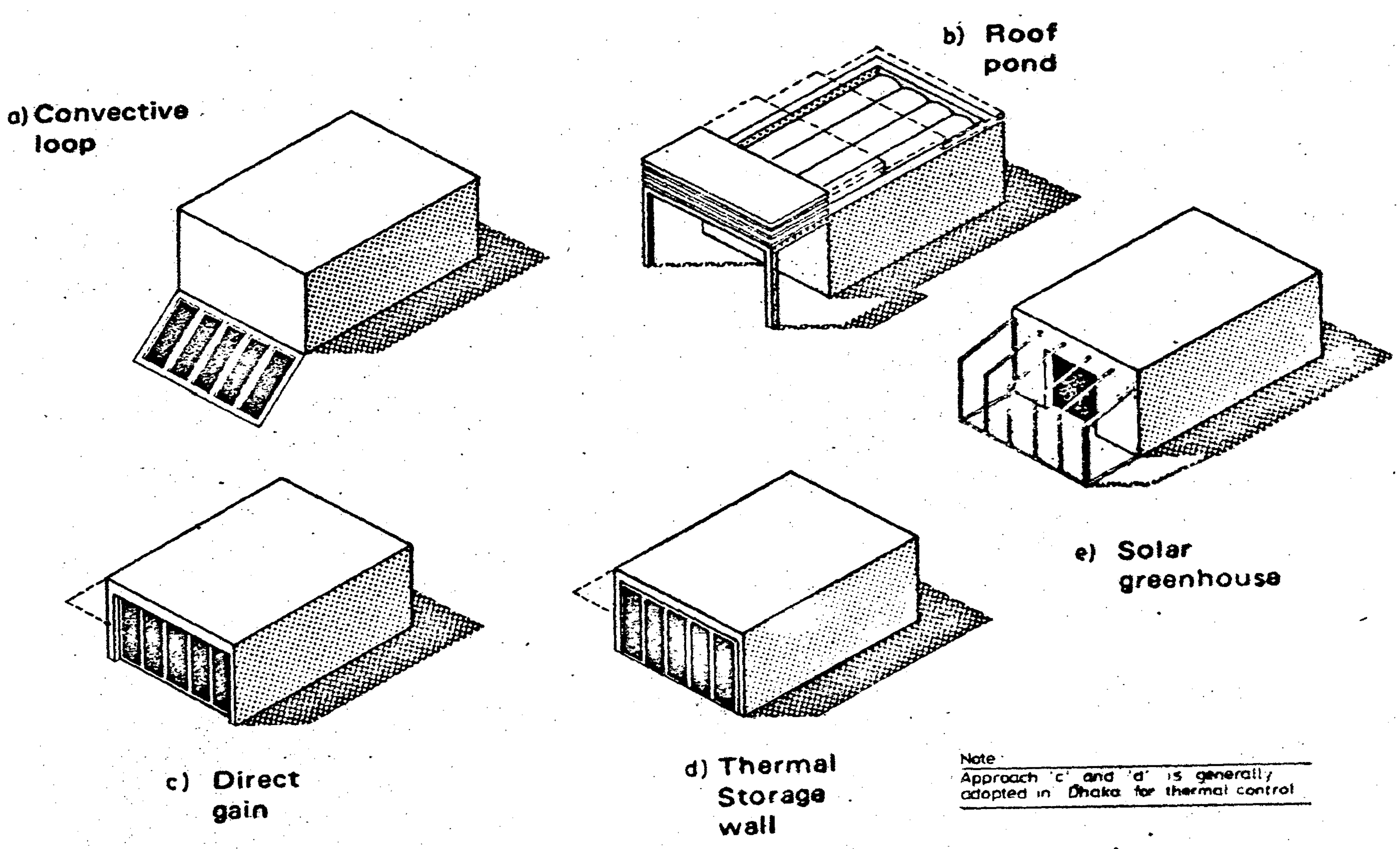


FIG:6 Bio-Climatic approach in design for thermal control (33) to the specific thermal environmental problems. They open or close their surfaces according to either favourable or adverse conditions. The vegetation in warm-humid areas grow more liberally in size and shape, this seems to bear an analogy to the formation of built forms for that region, as a few of the shaping forces e.g. temperature range are some what similar to human environmental need.

2.2.2 Optimum Proportion:

An optimum proportion is one which loses the minimum heat in winter and accepts least amount of radiation in summer. Therefore, optimum proportion of plan in warm humid regions is 1:1.7 (width to length) whereas a good proportion is about 1:3 in both cases the shape is elongated in the east-west direction(34). Research carried out by Olgyay(41) for main climates for given area of a house with different proportions gives following conclusion:

- The square form is not the optimum in any location
- All shapes elongated on the north-south axis work both in winter and summer with less effeciency than the square one.
- The optimum lies in every case in a form elongated some where along the east-west direction.

Performance will also vary with the configuration of facade (Fig 7 b,e) and nature of the built form as it changes the exposure condition of the building 'Umbrella' type (Fig.89), for example compared with terresed type, will have less exposed area to sun and more to wind, giving rise to convective heat loss. The variation of heat loss with increase in volumes is shown in Fig. 8 which is almost directly proportional.

2.2.3 Building shape and weight

One of the contributory factor to the thermal effeciency of the built-form is its shape. The smaller the

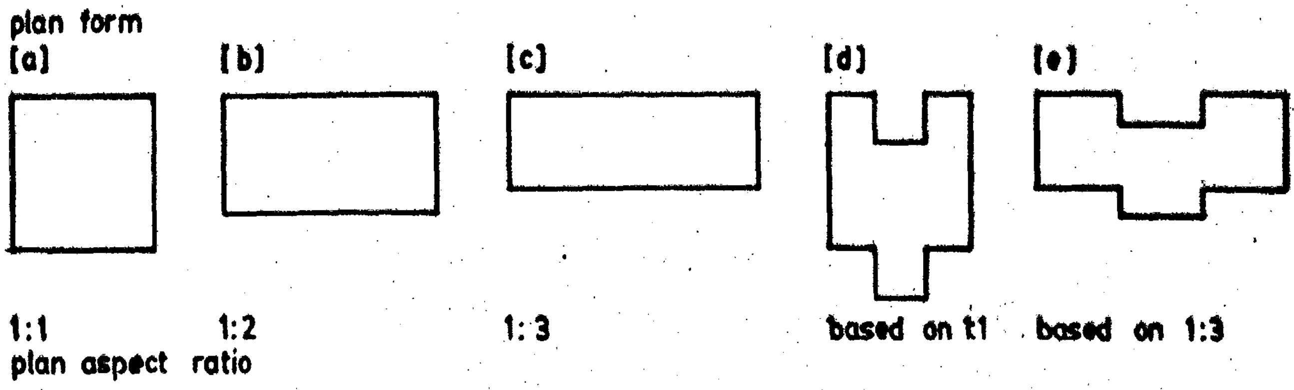


FIG.7 . VARIOUS PLAN FORMS USED AS BASIS FOR GRAPH(11)

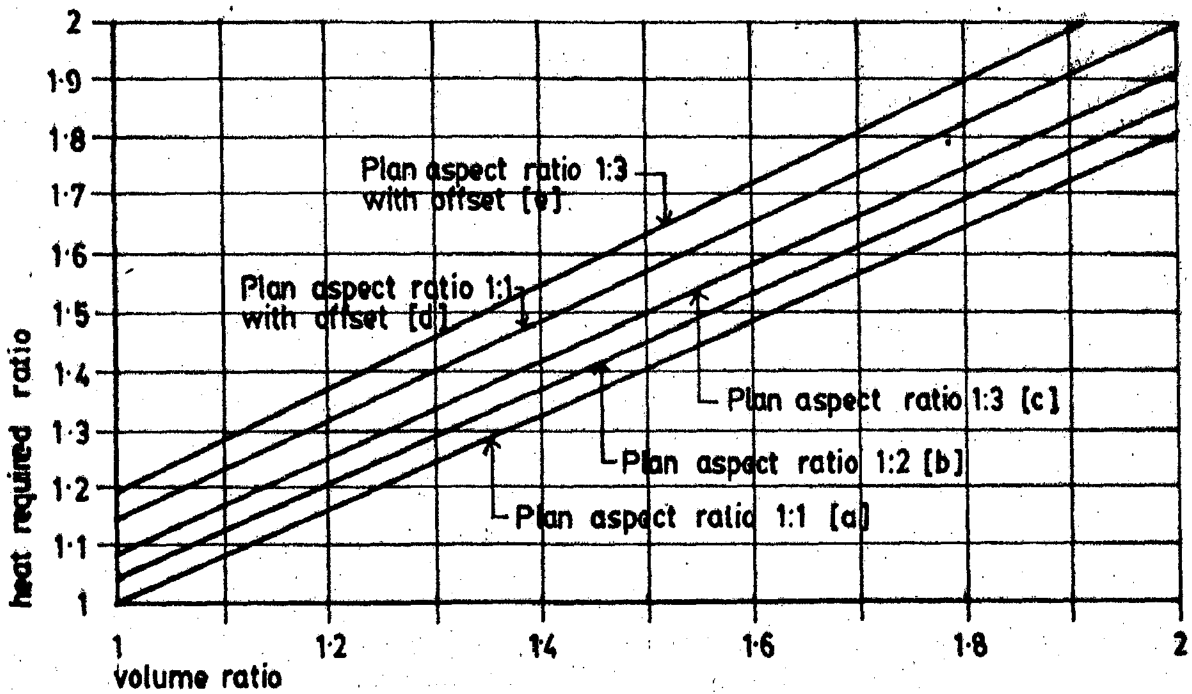


FIG. 8 , HEAT LOSS RATIO DIRECTLY VARIES WITH VOLUME RATIO (11)
(based on $100 m^2$ two storied dwelling with square plan form as unity)

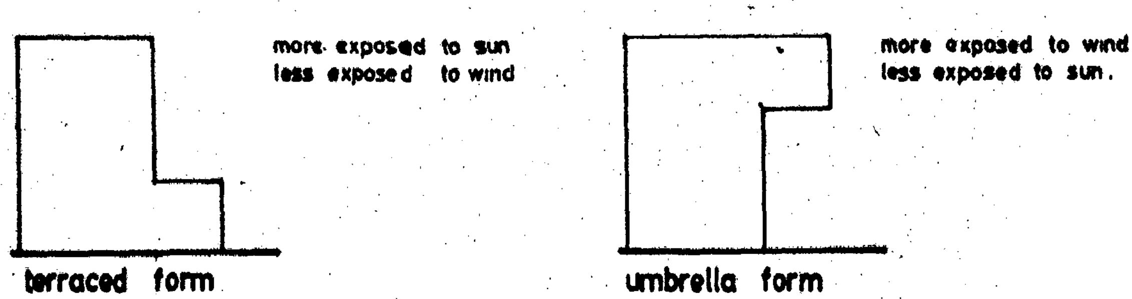


FIG.9 . NATURE OF BUILT_FORM(author)

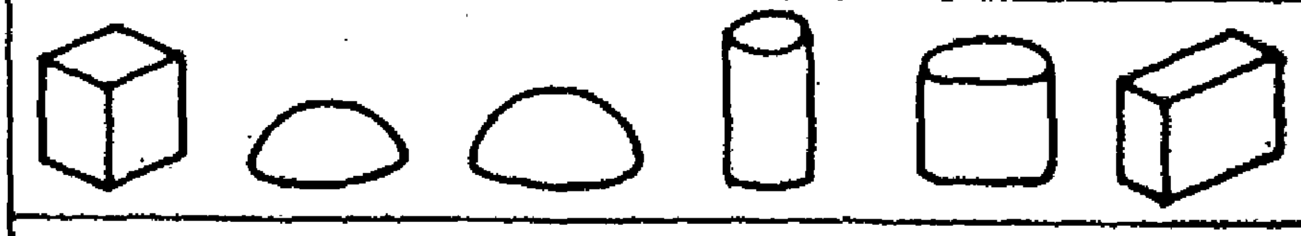
external surface area of the building - its walls and roof - the less it losses or gains heat from external environment. This is a directly proportional relationship. The variation of heat loss resulting from considerable variations of shape are shown in Fig .8 moving from economical 1:3 aspect ratio with offset(e) to a more compact square shape(a) results in about 20 % more heat gain(11). It appears, therefore, that variation in shape within these limits is not a major consideration in heat loss. This can be tremendously improved by combining with cross ventilation, using operable, shaded windows in windward side.

An exercise was carried out by Marsh(34) to study various basic geometric shapes, surface areas out of these shapes and their functional effeciency (Fig.10) and concluded that for all practical purpose any shape other than square and rectangular one would require an increase in floor area, when its surface area would exceed that of the square or rectangular plan building. Again rectangular dwelling of approximately the same area, the walls of which are in the ratio of 1:3.1, would have a total external surface area of over 11% greater than that of the square plan building.

Another study carried out by Sahu(44) for numerical valuation of surface area to floor area ratio for different geometrical envelope to cover same floor area (Fig.11) reveals similar facts as that of Marsh.

The effect of varying surface area can be illustraded in similar sized buildings. If a top floor unit is taken as representing the mean with regard to heat loss criteria, an intermediate floor gable unit would represent about 50 % of that mean, a middle terrace unit 94% , a semi-detached or and terrace unit about 120 % and or detached unit 151 % (Fig.12).

Based on the findings of Sahu(44), Marsh(34) and



total floor area [m²]	93.02	126.27	138.27	93.17	110.88	92.80
usable floor area [m²]	93.02	75.99	87.99	93.17	110.88	92.80
plan area [m²]	46.51	69.42	75.42	46.58	55.44	46.40
ceiling height [m]	2.3	2.0	2.0	2.3	2.3	2.3
overall height [m]	4.8	4.7	4.9	4.8	4.8	4.8
ratio of sides	1.1	–	–	–	–	1:3.1
plan dimensions [m]	6.82×6.82	9.4 dia.	9.8 dia.	7.7 dia.	8.4 dia.	3.87×11.99
surface area [m²] : walls	130.94	138.85	150.84	116.16	126.72	152.25
roof	46.51			46.58	55.44	46.40
	177.45			162.74	182.16	198.65
if semi-detached : walls	98.21	if semi-detached — long side: walls				94.70
roof	46.51	roof				46.40
	144.72					141.10
		short side: walls				133.68
		roof				46.40
						180.08

FIG: 10 The Shape of a Building related to its Surfce Area [34]

plan						
elevation						
SA : FA	4:1	4.75 : 1	1.8 : 1	3.66 : 1	1.65 : 1	2.65 : 1

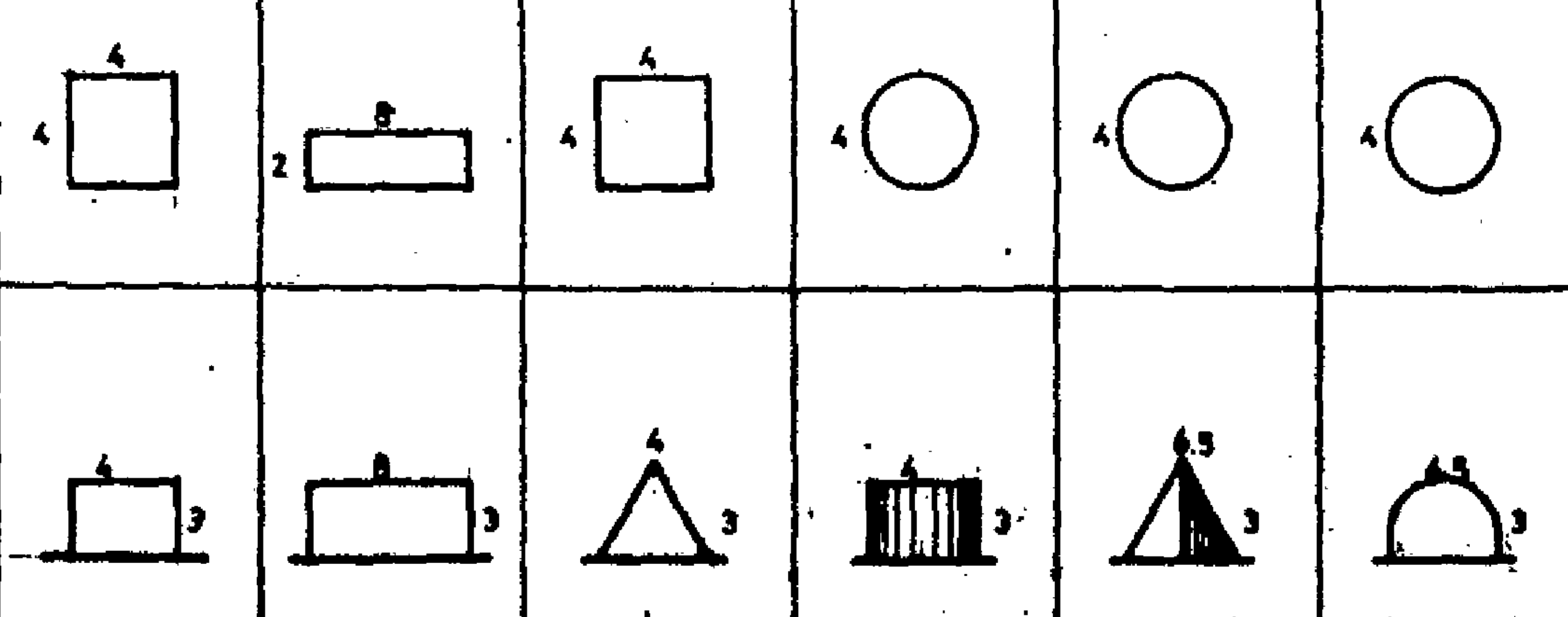
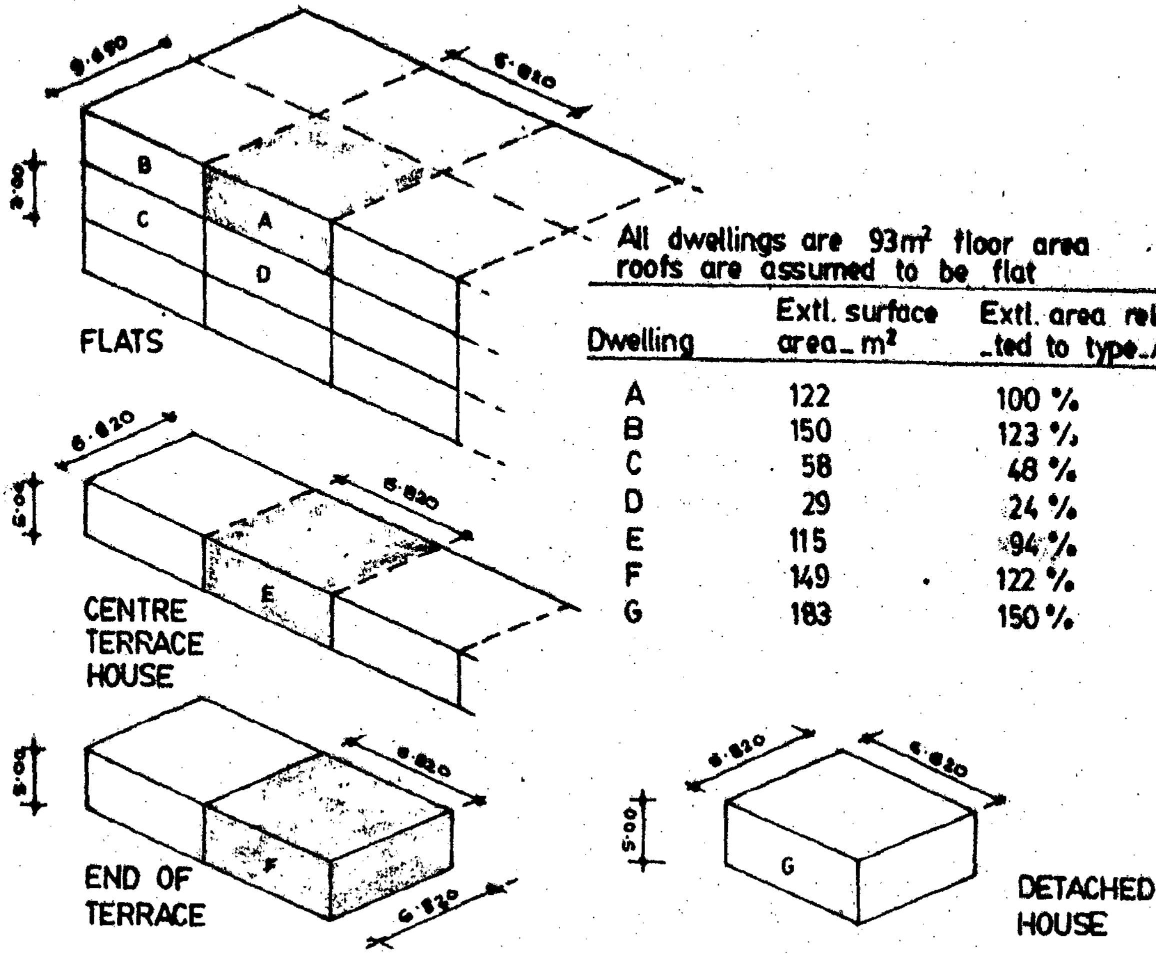


FIG: 11 Surface Area to Floor Area Ratio [SA:FA], for different geometrical envelope to cover same floor area [33]



All dwellings are 93m² floor area
roofs are assumed to be flat

Dwelling	Extl. surface area _ m²	Extl. area related to type A.
A	122	100 %
B	150	123 %
C	58	48 %
D	29	24 %
E	115	94 %
F	149	122 %
G	183	150 %

FIG.12. External surface area of different dwelling types (40)

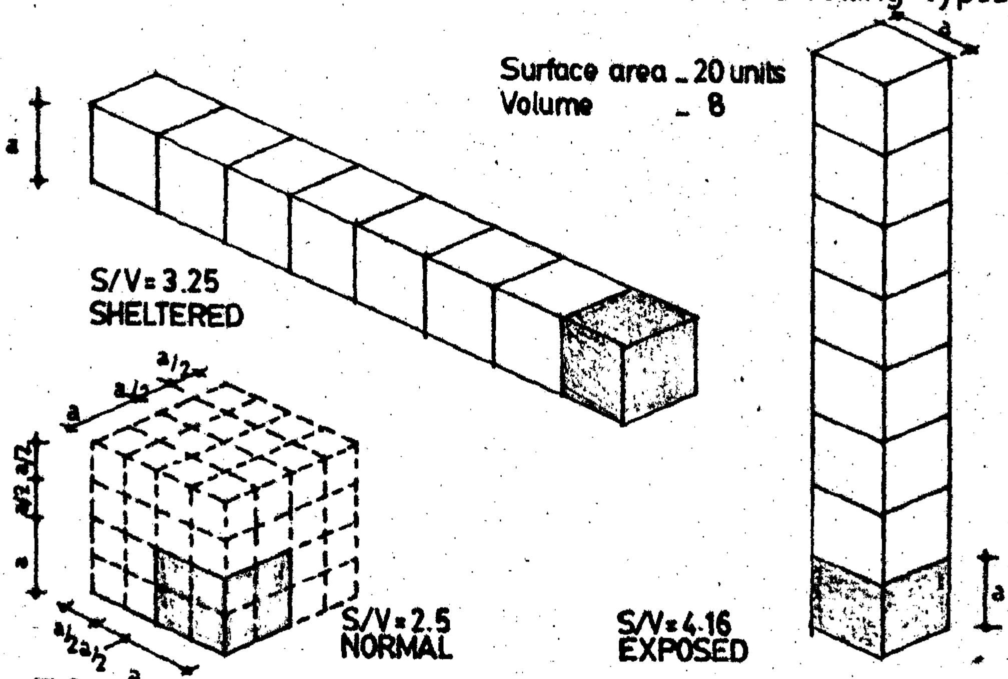


FIG.13. Grouping of built volume (author)

Olgyay(41) in favour of well oriented square or rectangular shaped buildings, the author did an exercise to assess the surface to volume ratio in different combinations as follows (Fig 13.).

- Exposed: Unscreened buildings in inland areas and for storeys above the fourth in towns; likely wind speed 9.0 m/s.
- Normal : Sub-urban houses and the third and fourth storeys of buildings in towns; likely wind speed 3.0 m/s.
- Sheltered:The first two storeys of buildings in towns or builtup areas, likely wind speed 1.0 m/s.

The conclusion is that the horizontal attachment of units perform better climatically when compared to vertical stacking or compact grouping.

2.3 Summary of discussion

2.3.1 With the help of equation 03 and 04, solar azimuth and altitude for different instants of the day by months is found out for Dhaka and sun path diagram is plotted. Equations 05 to 07 gives sun rise and sun set times.

2.3.2 Since no recorded solar radiation data is available for Dhaka but sun shine hours are available from Bangladesh Meteorological Department, equation 28 is used for assessment of solar radiation.

2.3.3 Equations 08 to 27 are employed for cross checking the values found out graphically for solar radiation by the solar radiation protractor in chapter six.

2.3.4 Study reveals that plan size and shape for Dhaka architecture should be very liberal but oriented against the sun and exposed to wind.

2.3.5 Ideal Plan is a rectangle with proportions 1:7 (width to length), whereas good proportion is 1:3 and elongated in east-west direction. Plan and elevation with offsets and staggering is even better for Dhaka.

2.3.6 Volume effect of building shape is not much significant in Dhaka climate and recommended percentage of openings in north and south facades is about 40% .

2.3.7 Buildings in a row, to shade east and west walls of each other, and of low rise are thermally more effecient for Dhaka.

3.0 SUN AND THE DESIGN PROCESS

3.1 Characteristics of Tropical Climates

Tropical climates are broadly divided into hot dry and warm-humid types by Koenighberger(29), Fry(23), Muktadir(39) etc, on the basis of following parameters:

a. Air temperature: Mean maximum range for warm-humid and hot dry climates is 27-32°C and 40-50°C respectively, whereas mean minima ranges between 10 to 18°C and 20 to 25°C respectively for above types of climate.

b. Diurnal and annual range of temperature: For warm-humid and hot-dry climates diurnal range is between 3-10 deg C and 17-22 deg C respectively. Annual range is between 8-15 deg C and 12-25 deg C for warm- humid and hot-dry zones respectively.

c. Relative humidity (R.H.): It is between 55% to almost 100 % for warm humid and 10-60% for hot dry. Vapour pressure is steady between 2000-3000 N/m^2 for warm-humids and for hot dry's, it is normally between 750-1500 N/m^2.

d. Annual rainfall: 2000-5000 mm/year and 100 mm/hr for short period in warm-humid climates and 50-150 mm/year in hot-dry climates.

e. Sky Condition: Fairly cloudy throughout the year, cloud cover between 50 to almost 100 %. Thinly overcast sky is bright, heavily overcast sky is dull in warm-humid regions. In the hot-dry region, the sky is clear and blue. Dust suspended in air may produce diffused light causing glare

f. Solar radiation: In the warm-humid regions, solar radiation is partly reflected, partly scattered by the cloud blanket or high vapour content of the atmosphere. Therefore the radiation reaching the ground is diffused but strong and cause painful sky glare. Cloud and atmospheric content also reduces long wave radiation from the surface of the earth. In the hot-dry regions there is direct and strong solar radiation during the day. After sun set there is easy long wave radiation towards the cold night sky.

g. Wind velocity: In the warm-humid regions, wind velocity is typically low, 2-7 m/s. Gust can be upto 30m/s and hurricane and cyclone can be upto 45-70 m/s. There can be one or two dominent prevailing wind directions.

In the hot dry regions, winds are mostly local. Temperature inversion causes whirl winds. The wind is hot and frequently dust storm occur.

h. Vegetation: In warm-humid climates, vegetation grows quickly, sub-soil water table is high, ground may be water logged, little light is reflected from the ground. But in hot-dry regions, vegetation is sparse and difficult to attain, reflective ground can cause glare.

i. Special Characteristics: In warm-humid regions high humidity accelerates mould and algae growth, rusting and rotting, hence, organic building materials tend to decay rapidly. Mosquitoes and other insects abound. Thunder storms are accompanied by frequent air to air electrical discharges.

In hot-dry climates, there is sand storms, excessive expansion and contraction may cause cracks in the buildings.

3.2 Solar radiation and the Building:

Bioclimatic methods of sun controls in building came long before the term came into use. The four principal techniques for warm humid regions are:

a. Allowing sun light penetration through windows during winter and/or exclude sun light during summer. Later method is more importent for Dhaka. This effect direct heat gain by the indoor materials with eventual rise in the MRT of the indoor surfaces and indoor temperature. This can be by for the greatest source of heat gain in an indoor space(24).

b. Natural ventilation to cool a building in a warm humid climate (appendix-2,3,4).

c. Storing warmth or coolth, through the use of a thermal store, which could consist of massive walls or floor, or a separate mass of store or water frequently kept underground(17). These methods are not frequently used in buildings of Dhaka, as the temperature difference indoors and outdoors is not much.

d. Insulating the interior from the exterior to prevent undesired heating or cooling by radiation or conduction(17). The method is popular for air conditioned buildings.

Solar irradiation on the external surface of the envelope of the form causes heat gain and a portion of this heat propagates through the materials inwards resulting eventually in rise in the MRT of the indoor surfaces and in the indoor air temperature. Thermal storage and insulation though not popular in Dhaka buildings, yet it can be used to perform by the same part of the buildings, as for example by massive walls. Old buildings of Dhaka(e.g. Plate-1) are seen to make use of these principles.

3.3 Thermophysical Properties of Materials and Construction

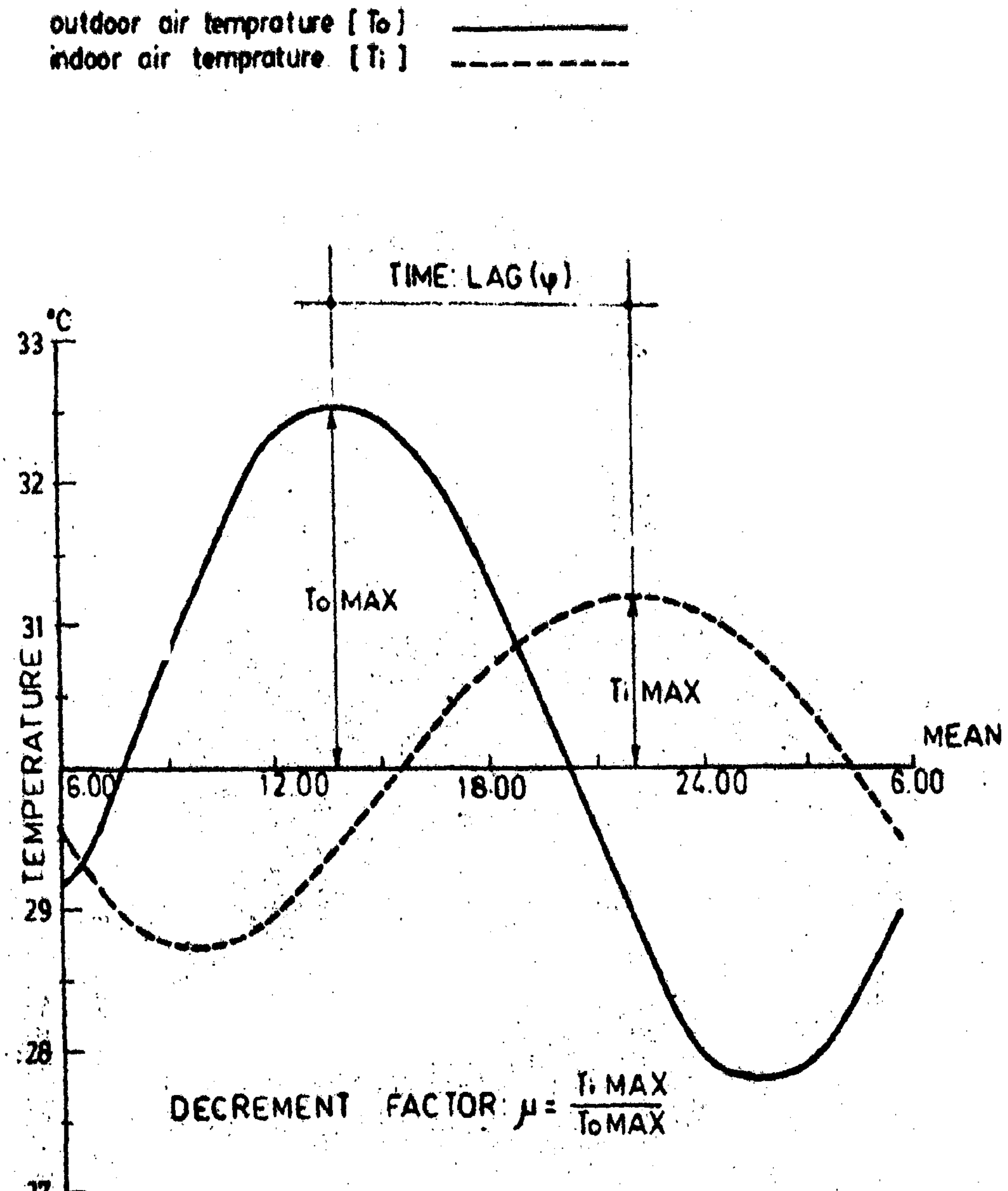
The effects on the indoor thermal environment due to solar irradiation on the external surface of the envelope will depend, as far as the fabric of the form is concerned on the thermophysical properties of the materials and construction of the envelope(39). When solar radiation is incident on the external surface of the envelope, a part of the incident radiation is reflected and the remainder is absorbed into the material elevating its temperature. Part of the absorbed component is stored in the material to be dissipated to the surroundings later, while the rest flows through the material to the cooler indoor surfaces and eventually to the indoor air(17). Thus the selective absorptivity and emissivity characteristics of the surface materials can form an effective diffence against radiation impacts and the extent of solar heat infilteration into the space through the materials of the envelope is partly dependent on these characteristics of the surface of envelope.

Materials which reflect rather than absorb solar radiation and which more readily release the absorbed quantity as long wave thermal radiation will cause lower temperature within the structure and hence lower heat gain by indoor space. The quantities characterizing periodic change in indoor thermal conditions are the decrement factor(μ) and the time-leg(ϕ) as shown in Fig.14 . The first effect is caused by the insulation value of the material of the envelope characterised by the U-value, while the second effect depends on the heat storage value of the materials(29).

In Dhaka climate, where there is small temperature difference between the inside and the outside as a result of open planning and cross-ventilation, the heat flow will be small any way, and thermal insulation should not normally be a critical factor. However, since the heat gain situation with strong solar radiation is infact controlled by the Sol-air temperature value and not by the air temperature alone, restriction of sun is very important in these parts of the envelope of the building which are most exposed to solar radiation contributing to the undesirable heat gain in the space(39).

3.4 Heat transfer through envelope

The heat storage value or thermal capacity



Note: reading on a warm july day with cloudy night in Dhaka for fully exposed guard room with 25 cm. brick wall, 10cm RCC roof slab & openings on north and south.

FIG:14. Diurnal fluctuation of temperature Indoors and Outdoors. (author) controls the rate of temperature change that is propagated through the material. Small diurnal variations, as in Dhaka, do not help the building to cool off suffeciently at night to allow the storage of heat during the day..Under such condition the principal of heat storage can not thus be effectively used. Rate of heat transfer, under steady state, through opaque elements is mathematically represented as follows:

$$q = U.A.(t_o - t_1) \qquad 29.$$

where, q = Rate of heat flow in watts(W)

U = Overall thermal transmittance value W/m^2 deg C

A = Area of element in m^2

$t_o - t_1$ = Temperature difference, air-to-air across the element in deg C.

Heat transfer through a non-opaque element depends upon angle of incidence of solar radiation, which is maximum at normal and minimum at parallel. Total rate of heat transfer through unit area of glass(qg) is expressed as follows:

$$qg = A[(F_D I_D + F_d I_d) + U(t_o - t_1)] \qquad 30.$$

where F_D, F_d = Dimensionless ratio of solar heat gain to solar radiation incident on glass for direct and diffused solar radiation components respectively.

I_D, I_d= Components of direct and diffused solar radiation encident on material in wall/m^2.

U, t_o, t_i, A etc. carry usual meaning as in eq.29

$F_D I_D + F_d I_d$ for ordinary clear glass, which is considered perfect non-opaque body, is called Solar heat gain factor (SHGF) for other fenestrations it is simply termed as Solar heat gain(SHG), therefore shading Coefficient(S)is(52):

$$S = \frac{\text{SHG for fenestration under consideration}}{\text{SHGF for ordinary clear glass}}$$

$$= \frac{F_D I_D + F_d I_d}{(F_D I_D + F_d I_d)_1} \qquad 30.$$

Equation 30 can be expressed in terms of physical properties of the glazing material as

$$qg = A[I\gamma + \frac{h_i}{h_i + h_o} .a.I. + U(t_o - t_i)] \qquad 31.$$

where γ = transmittance of material for radiation.

a = absorptivity of solar radiation

h_i, h_o = inner and outer surface coeffecient of heat transfer by material.

All other symbols carry usual meaning.

3.5 Generalization of heat transfer formula

It is seen that heat infiltration through the materials of the envelope of the form will depend on a large number of thermophysical properties of the materials and construction of the envelope e.g. absorptivity (a) and emissivity (e) of surface materials, surface conductance and thermal conductivity, thickness and density and position of the insulation. It is possible to combine these factors and reduce them to three main variables which can be used to specify the thermal performance of a component of the form required under given conditions in a given climate. These variables are:

Air to air transmittance (U-value) of a construction in w/m^2 deg C and represented by

$$U = \frac{1}{R} = \frac{1}{[\frac{1}{h_i} + \frac{1}{h_o} + (\frac{d_1}{K_i} + \frac{d_2}{K_2} + \ldots + \frac{d_n}{K_n})]} \qquad 32$$

where, h_i, h_o = Coeffecient of inner and outer surface respectively.

$K_1, K_2..$ = Thermal conductivity of different materials

$d_1, d_2..$ = Thickness of respective materials comprising the component.

- Solar Heat Gain factor(SHGF): Heat flow rate through the construction due to solar radiation expressed as a fraction of the incident solar radiation(39). From the sol-air temperature concept:

$$T_s = T_o + \frac{I \times a}{f_o} \qquad 33.$$

Although above equation is well enough, yet to achieve better combined effect of solar radiation and ambient air condition(21), it can be extended to:

$$T_s = T_o + \frac{Ixa}{h_o} + (T_r - T_o)\frac{h_r}{h_o} \qquad 34.$$

where T_s = Sol-air temperature in ^oC

T_r = mean radient temperature of surrounding

h_r = external radiative surface coeffecient.

a, h_o, I etc.= carry usual meaning

But $T_s - T_o = \frac{Ixa}{h_o}$, thus extra heat flow rate per unit area due to radiation is given by.

$$q = \frac{I \times a}{h_o} .U \text{ in } w/m^2 \qquad 35.$$

From this the solar heat gain factor (SHGF) is given by:

$$\frac{q}{I} = \frac{a \times U}{h_o} \text{ (non dimensional)} \qquad 36.$$

From experience it is found that the solar heat gain factor (q/I) should not exceed 0.04 in warm humid climates and is reasonable to assume $h_o = 20\ w/m^2$ deg C thus, giving a target value of a x U for warm humid climate equal to 0.8(29).

Decrement factor and time lag: The amplitude attenuation and the shift of phase respectively of the internal temperature cycle in relation to the external cycle (Fig.14).

3.6 Summary of Discussion:

From the discussion so far, it is clear that heat gain through the materials of the envelope of the form caused by solar irradiation on the external surface will depend on:

a) Duration of the solar irradiation received on the surface.

b) Intensity of solar irradiation received on the surface.

c) Area of the surface exposed to solar irradiation.

d) The extent of solar heat infiltration through the envelope expressed as a fraction of the incident solar radiation on its surface.

e) The decrement factor and the time-lag characteristics of the envelope, but thermal insulation is not normally a critical factor in the thermal designs for Dhaka.

4.0 ROLE OF SUN ON COMFORT CONDITIONS AND THE GENERAL DESIGN CRITERIA FOR DHAKA

4.1 Climate of Dhaka in brief:

The climate of Dhaka is a warm-humid as seen from the summarized data (appendix:1)(6). The characteristic points are given below:

a. Air temperature moderately high (12-34°C, small diurnal range, seldom exceeds normal skin temperature(32-37°C).

b. High relative humidity (87% average) in all seasons, coupled with moderate to high temperature produces skicky conditions.

c. Heavy Clouds (about 273 days in a year) and water vapour reduces and diffuses solar radiation. 2500-2600 bright sunny hours are recorded of which about 1500 hours is in November to april.

d. Wind speed is generally between 2- 6 m/s, variable and generally constant in direction i.e. 125°-225 in March to September, Winter winds are below 1.5 m/s in speed.

e. Rainfall amount is quite high (1800-2200 mm/yr) and an exposure to rainfall is moderate to low(9). Intensity of rainfall for small duration may be very high(36).

f. Barometric pressure fluctuates (daily range 3 mks) which is moderately high. The air comes in and out of the soil in proportion to barometric pressure and with reference to the wind. If there is much water in soil, the air carries with it water vapours, and is cold, and such site is called damp and is unhealthy(37).

g. Climate favours vegetation, plant cover reduces ground reflection and ground heating.

4.2 Analysis of Thermal Comfort for Dhaka:

4.2.1 General discussion on thermal indices:

In summarizing the reliability of some important thermal indices inferred from the correlation observed between their prediction and experimental results of the physiological examinations carried out, the following conclusions are suggested(25).

- Effective Temperature(E.T.): E.T. index appears to be the least reliable in producing the expected physiological and sensory responses, both in comfortable conditions and under heat stress.

- Resultant Temperature(R.T.): The reliability seems to be satisfactory in predicting responses of the people at rest or engaged in sedentary activity.

- The predicted Four Hour Sweet Rate($P._4.S.R.$): It is satisfactory under light to medium heat stress conditions for people at rest or engaged in light to medium work. Under severe heat stress it is still reliable in predicting the sweet rate, but these responses alone is not important, and so under these conditions the index is less satisfactory for predicting physiological strain.

- Heat Stress Index(HSI): It is suitable for analysing the relative contribution of the various factors resulting in thermal stress, but is not suitable for predicting quantitive physiological responses to the stress.

- Index of Thermal Stress(ITS): The individual contribution of metabic and environmental factors can be analysed and for prediction of the physiological strain imposed on resting and working people.

It is reliable in the range of conditions between comfort and severe stress, provided that thermal equilibrium can be maintained. Beyond this limit the index does not apply.

The table 04, summarizes the nominal range of environmental factors covered by each of the indices.

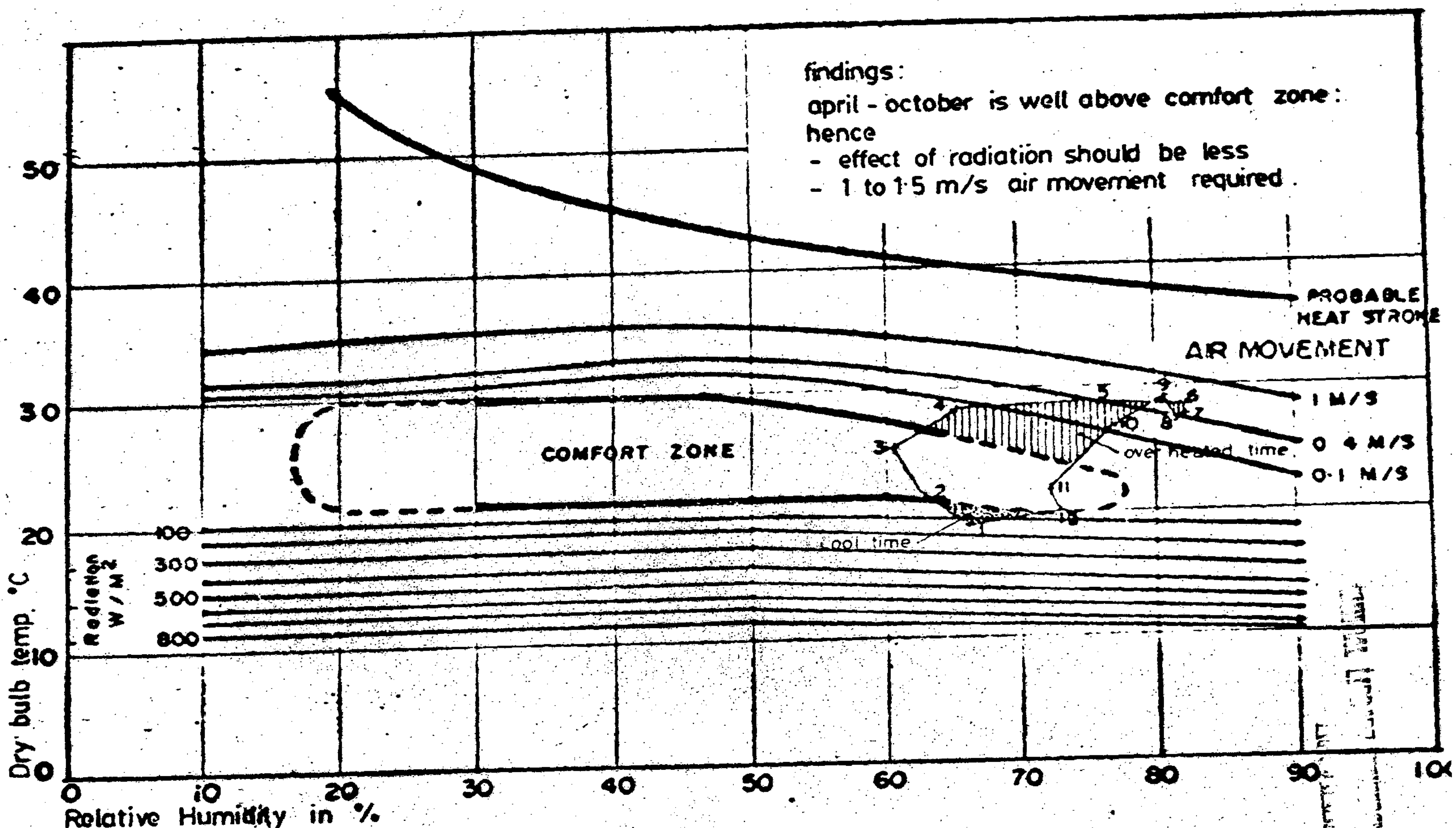
Table 04. Range of the indices

Index	Metabolic Rate (K cal/h)	D.B.T. (°C)	W.B.T (°C)	Air Vel. (m/s)
Effective Temperature	Rest only	1- 43	1- 43	0.1 - 3.5
Resultant Temperature	Rest only	18- 45	18- 45	0.1 - 3.0
$P._4S.R.$	100-350	27-55	15- 36	0.05- 2.5
Heat Stress Index	100-500	27- 60	15- 35	0.25-10.0
Index of Thermal Stress	100-600	20- 55	15- 55	0.1 - 3.5

4.2.2 Thermal Indices Suitable for Dhaka (Bangladesh)

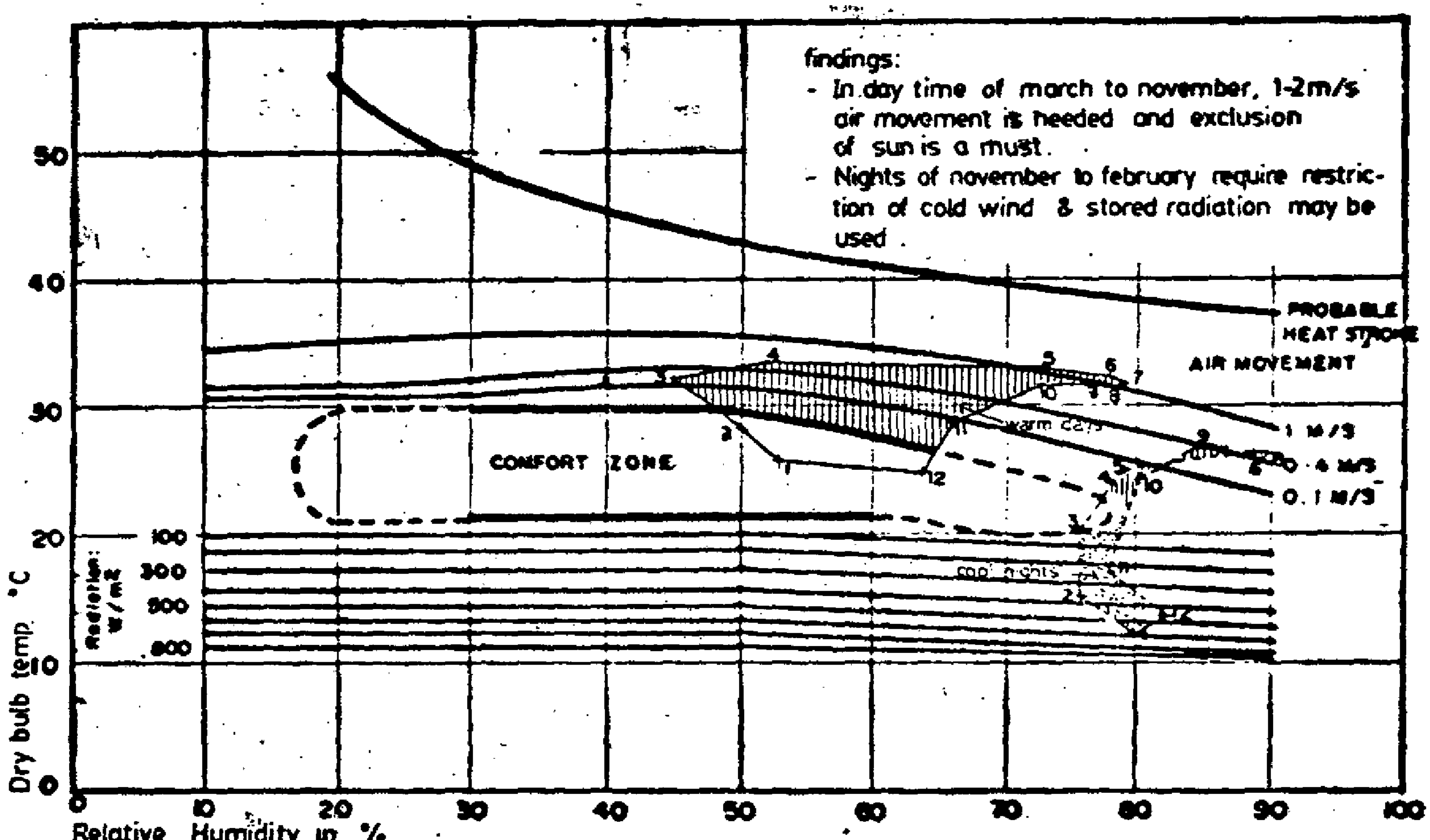
There are two more indices namely Bio-Climatic Chart and Tropical Summer Index, which are found to be more dependable for Bangladesh conditions and hence, are discussed in little detail.

(a) The comfort zone and defining it for Dhaka using Bio-Climatic Chart: Victor Olgyay(41) arrived at the idea that since the four components, namely, the air temperature, the relative humidity, the air velocity and the radiation, are each controlable by different means, a single figure index can be constructed. Using published experimental data as a basis he constructed a bio-climatic chart for temperate climates. Revising some values, Koenighberger(29) presented a modified chart for warm climates that can be conveniently used for the whole tropical region.



RH% NUMBERS IN THE GRAPH INDICATE MONTH OF THE YEAR
POINTS ARE PLOTTED WITH AVERAGE VALUES OF TEMP. & R. H.

FIG-15. AVERAGE THERMAL CONDITION BY MONTHS FOR DHAKA. (author)



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.15. DIURNAL THERMAL CONDITION BY MONTHS FOR DHAKA. (author)

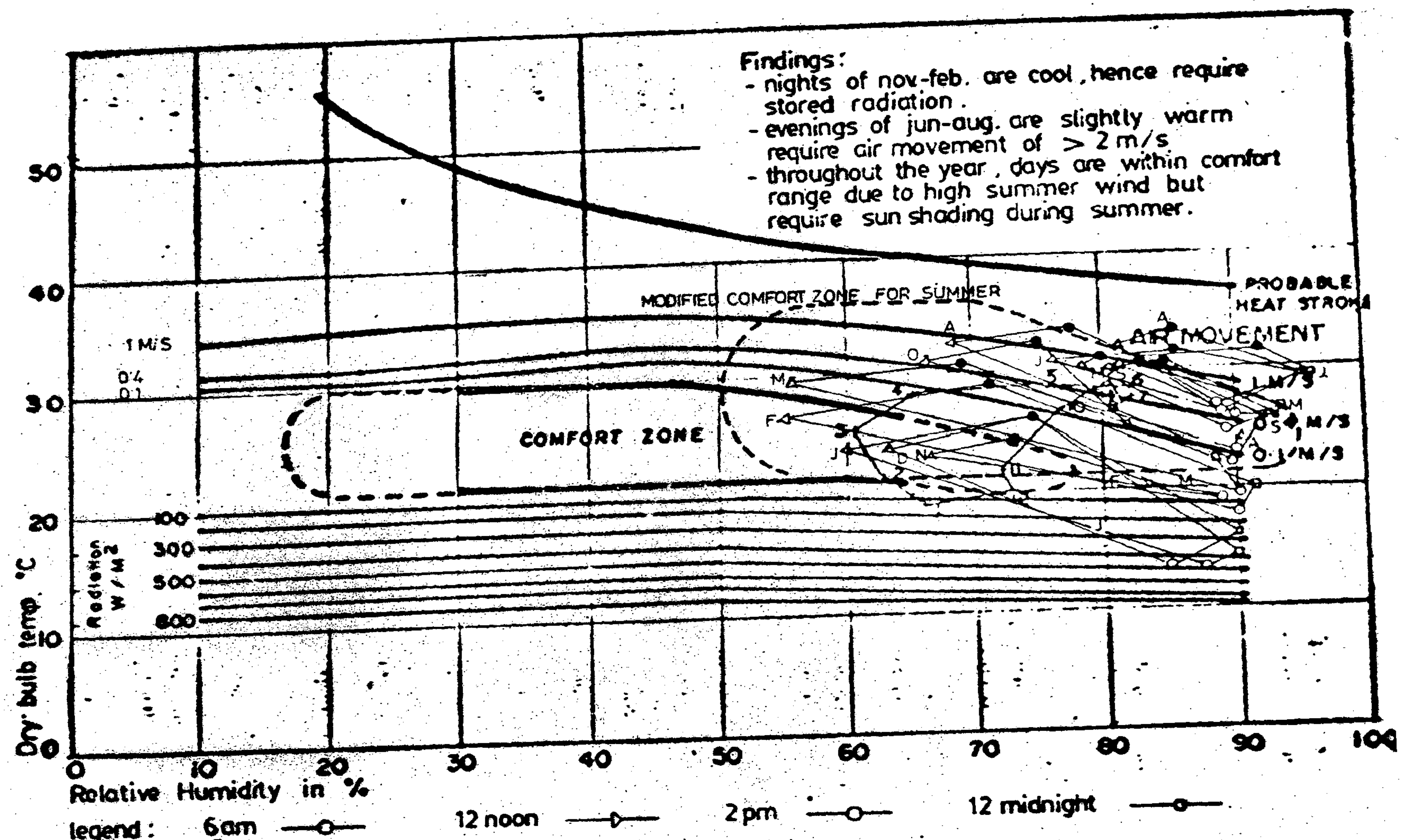


FIG: 17 MONTHLY THERMAL CONDITIONS AT VARIOUS INSTANTS OF THE DAY AT DHAKA. (author)

Climatic data of Dhaka have been plotted on the bio-climatic chart with three different parameters. (Fig 15 , 16 , 17). The three chart shows that during summer months the prevailing conditions are above the comfort zones due to high temperature and humidity. So continuous movement of air between 1 and 2 m/s is necessary to attain reasonable comfort level. And also the effect of radiation should be less. Charts also show that day time of winter months are within comfort zone and are quite pleasent. Nights are cold and below comfort zone. Nights of rest of the period of year are pleasent and days are a little warm but not very un-pleasent. For winter months no comfort ventilation is required, cold wind should be restricted at nights. Direct sun rays should be allowed to enter the interior spaces. In moderate months air flow during day time will bring comfort conditions.

(b) Prediction of thermal comfort for Dhaka by Tropical Summer Index(TSI): The basic criterion for an effecient building, from climatic point of view is its ability to modify the external climate into some thing indoors which produce none or minimum thermal stresses on the human body. Sharma(12) developed an index called Tropical Summer Index(TSI) which combines into a single value the effect of air temperature, humidity, air motion and radiation on the thermal sensation of human subjects. It is defined as that temperature of still air at 50% R.H. which induces the same thermal sensation as the given environmental conditions. The numerical value of the TSI is given by the equation:

$$TSI = 0.308\, t_w + 0.743\, db - 2.06\sqrt{V} + 0.8 \qquad 37.$$

where t_w = wet bulb temperature, $^\circ C$

db = dry bulb temperature, $^\circ C$

V = velocity of air, m/s

and TSI = Tropical Summer Index, $^\circ C$.

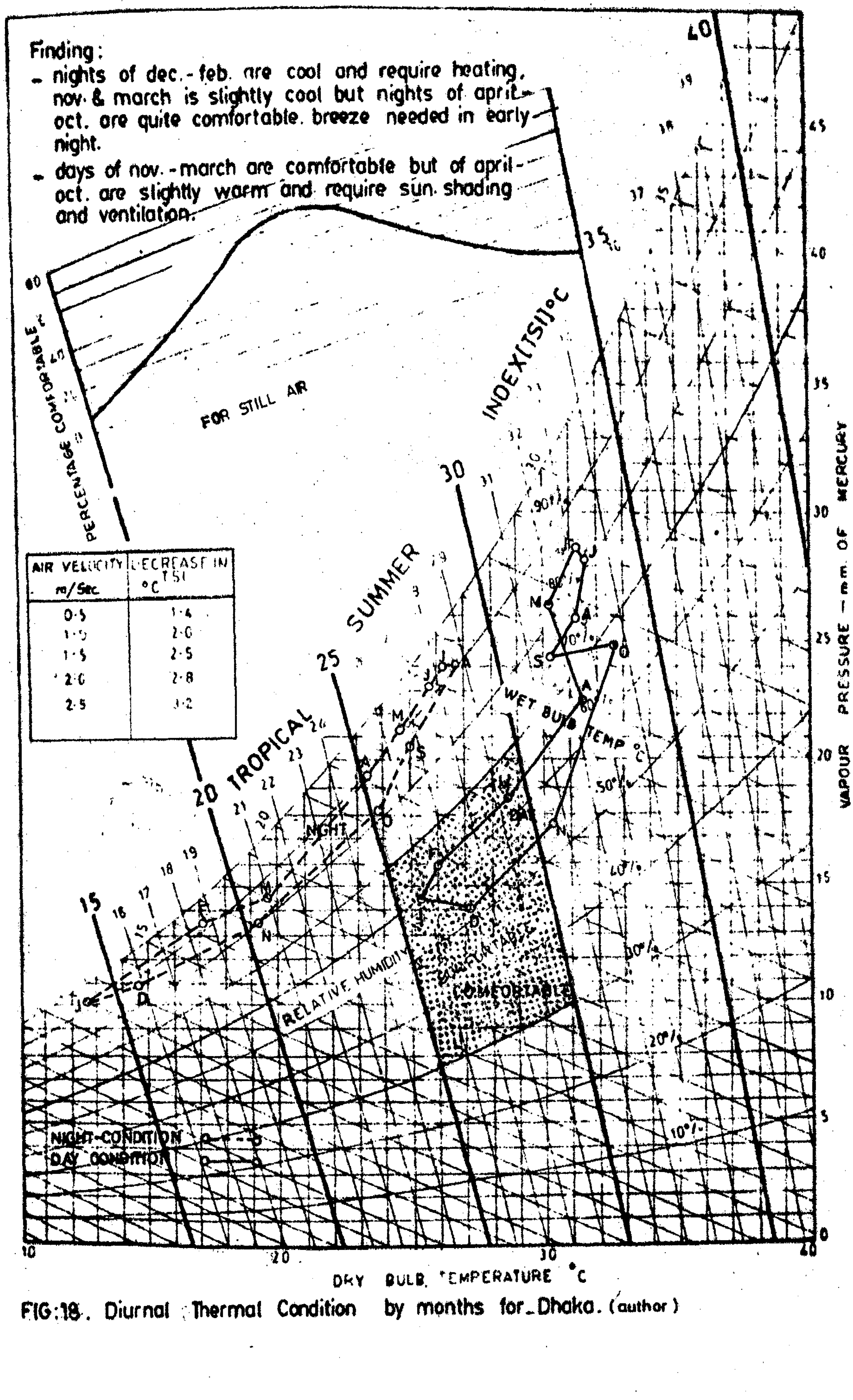


FIG:18. Diurnal Thermal Condition by months for Dhaka. (author)

It is found that more than 60% of thermally comfortable assessments lie at a TSI value of about 27°C, but safely, the range is 25-30 deg C. The chart in Fig.25 is perfectly valid for indoor conditions of buildings. The TSI lines, shown, are for still air conditions and the needed reduction in TSI values with increasing air motion are presented as inset in the same figure. Monthly day and night TSI for Dhaka is ploted in Fig.18 for still air and the TSI values with recorded wind data is shown in table.05, below:

Table 05. TSI Range for Dhaka by Months

		J	F	M	A	M	J	J	A	S	O	N	D
WBT	Max	19.2	20.5	20.5	24.0	25.7	26.0	27.0	26.5	26.2	26.0	25.3	21.5
°C	Min	11.5	13.3	17.5	22.0	23.0	25.0	25.2	25.8	22.4	22.4	18.2	12.5
DBT	Max	25.8	27.3	31.0	34.1	30.8	31.9	32.4	33.0	30.8	31.8	24.8	25.7
°C	Min	12.3	18.5	19.8	23.3	24.9	26.0	26.3	26.6	25.6	23.6	18.6	14.4
Air Vel. m/s		.8	1.4	1.7	2.6	2.7	1.9	2.2	2.1	2.1	.7	.3	.8
TSI	Max	24.0	24.8	27.5	30.2	28.2	29.7	30.2	30.5	28.8	30.8	29.6	24.7
°C	Min	11.6	16.2	18.2	21.6	23.0	25.0	25.1	25.5	23.7	23.5	19.1	13.5

The Fig.18 and table.05 confirms the results of bio-climatic chart discussed before (art.4 .2.2(a)], and hence, same corrective design measures are recommended to attain comfort condition indoors i.e. Manipulation of solar radiation and light into the building. The required value of TSI can be employed for fenestration design directly with the help of nomogram given in appendix:13(32)

4.3 Criteria and Principle of Design in Dhaka

From the recommendations of Olgyay(41), Koenisberger(29), Givoni(26) etc. (appendix:8) and in places authors own professional judgement, insight and vision, based on studies is used to interprete certain phenomena and make inferences. At times, available data were suplemented with authors personal experiences and observation (appendix-8).

The following design criterion is formed in general for the architectural design for dhaka, therefore, specific site and building must be studied for better performance of built form.

4.3.1 Form and Planning:

(a) Spaces to be opened up to the breeze with proper configuration of building, proper orientation of the inlets and proper sizes and locations of the inlets and outlets (appendix- 2,3,4). The primary comfort requirement in Dhak is for air motion but even, here, winds incident to wall at upto 45^{0} can provide satisfactory ventilation , giving a possible 90 deg. range of orientation(25).

(b) An open, elongated plan with single row rooms, will be most effective from cross ventilation point of view. A degree of variation in grouping of spaces is possible maintaining satisfactory ventilation (appendix-4).

(c) Rows of building blocks tend to reduce flow through buildings, unless grouping and spacing are properly considered(appendix-4).

(d) Plants and vegetation retards flow of air close to ground level, elevated plans can ensure better results. (appendix-5).

(e) Although solar radiation intensity is normally less than in hot dry regions, it is never the less a significant source of heat and therefore, its incidence on the building fabric and its entry into indoor spaces should be minimized (studied in next chapter) this can be done by:

(i) by orientation: south is perhaps the best
(ii) proper configuration of the building
(iii) Provision of overhang and other shading devices (appendix-7)

(f) Shading of all vertical surfaces will be much easier, if the building height is kept low.

(g) From the view point of solar gain, the best arrangement would be to orientate the built forms with long axis in east-west. This may some times conflict with the orientation requirements for wind flow such a conflict should be subjected to detailed analysis in every individual case.

(h) It may be remembered, however, that solar geometry can not be changed but skillful use of elements outside as wall projecting wing of a building or truss can change the direction of air flow.

(i) Exterior Solar Control: use of solar controls, such as louvres, overhangs and building facades to shade buildings and capture and direct prevailing wind to living areas and also protect the wall and glazing from precipitations.

(j) Interior Solar Control: blinds and drapes should be kept closed during day to prevent heat build-up and opened at night to release heat. Interior shading devices, if provided, should be flexible to allow windows to be opened for ventilation.

(k) Well ventilated and damp proof underground structure may be recommended for use of ground coolth in summer.

The projecting balconie, high ceilings, and large windows of mansons in calcutta or manila; the deep Varandas and post and lintel - homes of African planter; and the thin paper walls of houses in Indo-china are all designed to admit breez and keep out sun'(30). In brief, openness and shading must be the dominant characteristics of the form and planning in Dhaka.

4.3.2 External Spaces:

(a) The same principles i.e. free passage for air movement and shading are the two basic requirements, Choice of materials can also be important from climatic view point.

(b) Trees, Plantings, pargolas covered by climbing plants can be used for external space shading.

(c) Least porous i.e. concrete pavements with suitably located green punches may reduce the damping effect of a damp site as large range of barometric fluctuation effect over wet lose sub-soil is controlled(37).

(d) External spaces must facilitate a number of activities which are often carried out at outdoors.

4.3.3 Roof and Walls

(a) Because of small diurnal range of temperature, building fabric must be of low thermal capacity, this will require light weight construction.

(b) The roof is the most significant element from thermal view point because it will have the maximum of exposure to solar radiation over the day. Proper treatment of roof include:

- Use of reflective upper surface
- Use of double roofs with intermediate space ventilated.
- Using the ceiling below the roof with its upper surface highly reflective and having a good resistive insulation.
- the space above the ceiling should be ventilated

(c) Insulation in walls or roofs can be expensive, therefore an appropriate strategy can be to restrict the heat entry on the external surface through use of reflective materials. Also time lag characteristics of the construction need to be considered in relation to the activity pattern.

4.3.4 Air flow and openings:

(a) Opening must be generous and suitably arranged in relation to the prevailing breeze (appendix-2).

(b) The incoming flow must not adversely affected by outside objects and should not come over hot surfaces.

(c) Openings must be adequetly protected against rain penetration(9).

4.3.5 Light and view

(a) Direct sun light to be avoided for thermal reasons. The bright sky can provide sufficient light but would also cause glare. So view of the sky should be screened by shading devices or plants. As the sky luminance is much less near the horizon, a view of sky upto about 15° from the horizon is ideal (appendix 5).

(b) View of bright ground and sun lit louvre surfaces to be avoided. The strong luminance contrast between the view and the window surround can be reduced by:

- Painting the adjecent wall, a light colour.
- Painting the inside of window frame while.
- Other openings may be placed in the opposite or flanking walls to through some light onto the wall surrounding the window.
- Bright view can also be avoided by a vertical

strip window at the corner of the room. This would through light, onto the wall surface as a wash' thus reducing the luminance contrast of the opening.

(c) Day light is to be reflected from the ground up o ceiling which should be of light colour.

5.0 CASE STUDY

5.1 Introductory Remark

Dhaka, the capital city of Bangladesh, is situated on 23°45 N and 90°15 E at the bank of river Buri Ganga and was founded during the mughals. Most of the buildings of that period, made of common brick and surki, are ruined by the hostile climate. The vernacular architecture which is less durable, virtually suffered no change in style through the centuries. It is evident from the writings of travelers like Hiwan T'sang, Ibn-e-Batuta etc and what we see today.

Living example of old masonry architecture in Dhaka is only of late British colonial period. With the introduction of reinforced cement concrete in 60's the architecture of Dhaka entered into the present phase. Before entering into the analytical study of a particular environmental aspect the general architectural character of the region must be known.

In this chapter a very brief case study is carried out on the architecture of Dhaka to identity design features evolved through the ages due to the particualr local climate. Taking vernacular architecture as a basis, colonial architecture of Dhaka as a period of transition and contemporary architecture as a reality, random example is picked up from many cases for study to understand the basic criterion of thermal design in Dhaka.

In the case studies, besides taking direct performance observations from some buildings, the observation is supplemented with informations from published sources, authors own experience and professional judgement, relating to the termal performance of buildings in Dhaka. The studies are not in very detail and in some cases, relied on the subjective response of the users. The case studies done are as follows.

5.2 Vernacular Architecture:

Study of vernacular architecture reveals two typical vernacular elements that contributes to the thermal comfort(Fig: 19) i.e.

- element facilitating ventilation.
- elements protecting the building from sun.

Roof-form, roof overhang, opening in the roofs, latice work and low walls, etc together have contributed towards achieving thermal comfort in the interior spaces of dwellings of above mentioned region. Above observation is true for vernacular architecture of places with similar climate as well as architectural pattern. Figure 20 illustrates an ideal bio-climatic vernacular house of Dhaka, lebeled with characteristic features.

5.3 Thermal Performance of a Colonial residence:

This is a typical colonial building design, making use of locally employed responsive mechanism for thermal control. It is a double storied residential building with an area of 275 m^2/floor. The plan has an ideal aspect ratio of 1:7 (width to length) with offset. Massive exposed brick wall, timber shingled sloping roof and long verandahs are characteristic features of the house (Plate:01).

The south, east, north and west facades are about 280 m^2, 154 m^2, 240 m^2 and 136 m^2 respectively having 28% , 21% , 14% and 17% openings respectively. The building fabric takes care of the solar geometry. Massive wall and creation of a thermal buffer zone in cold wind direction, used in the building, is not a requirement for Dhaka's climate but blindiy followed from temperate architecture of U.K.(Fig: 22).

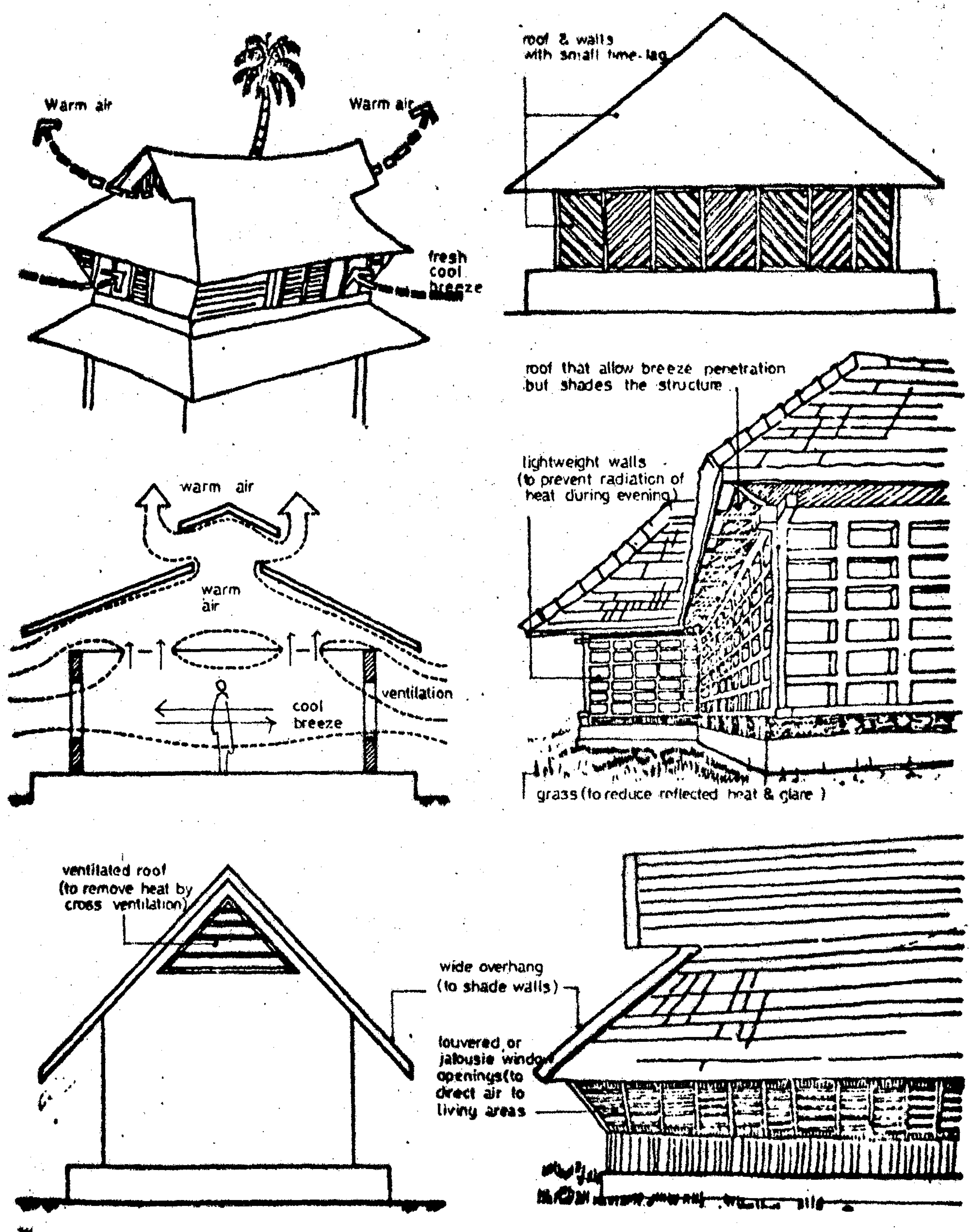


FIG:19 Vernacular architectural features for thermal control .(46).author

CLIMATE AND SHELTER CONSIDERATIONS—EXAMPLE STRUCTURE FOR WARM-HUMID REGION (20)

The example structure for the warmhumid region is elongated in the east-west direction. Design objectives are to: 1. reduce penetration of solar radiation, 2. remove inside heat from people, lights, etc., and 3. improve evaporative cooling conditions by natural ventilation. Air motion through window openings (oriented to intercept prevailing summer breezes) and roof ridge vent is shown by arrows on the sketch below. For effective attic ventilation, air should also enter through low inlets located in the soffits of the roof overhang.(20).

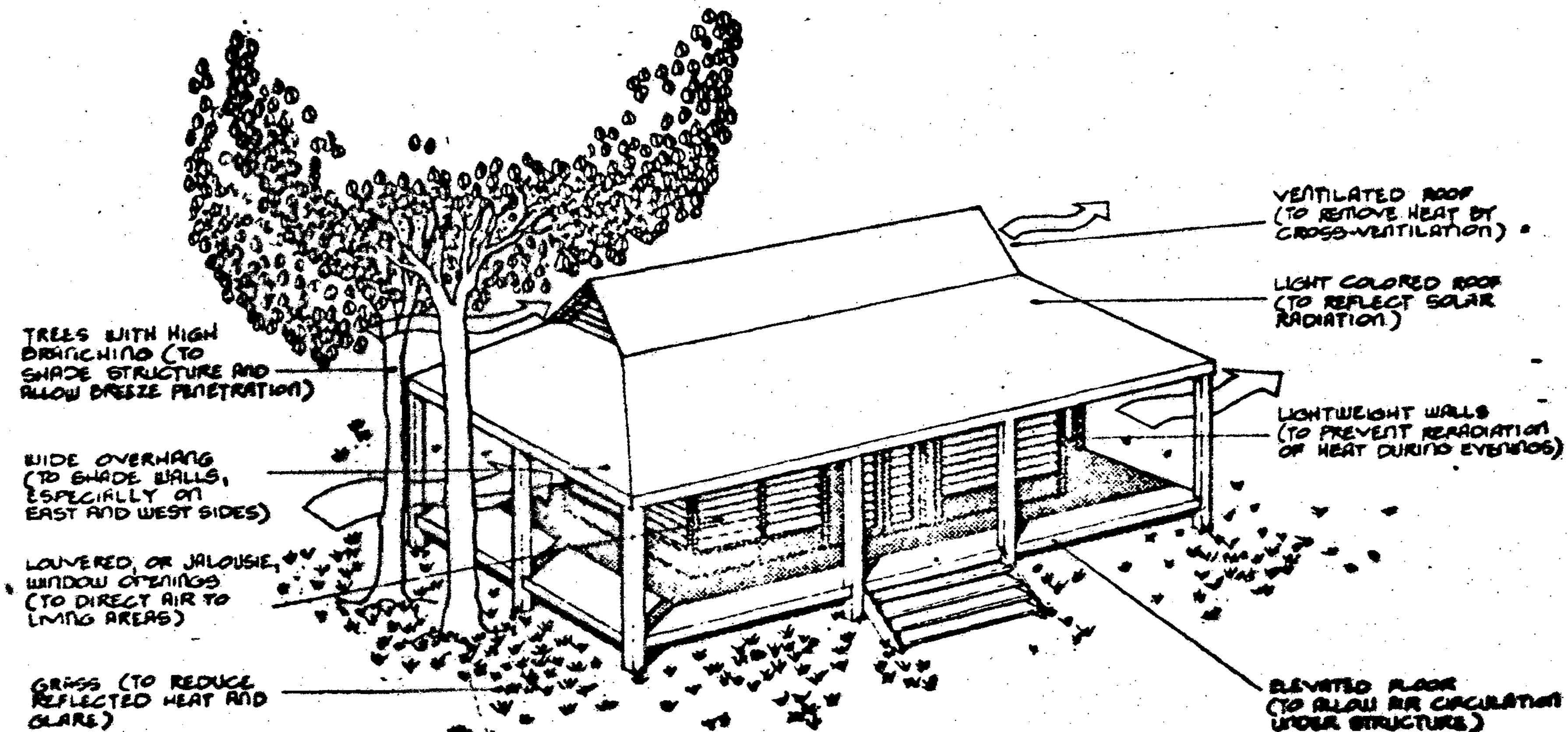


FIG: 20 TYPICAL BIO-CLIMATIC ARCHITECTURE OF BANGLADESH.

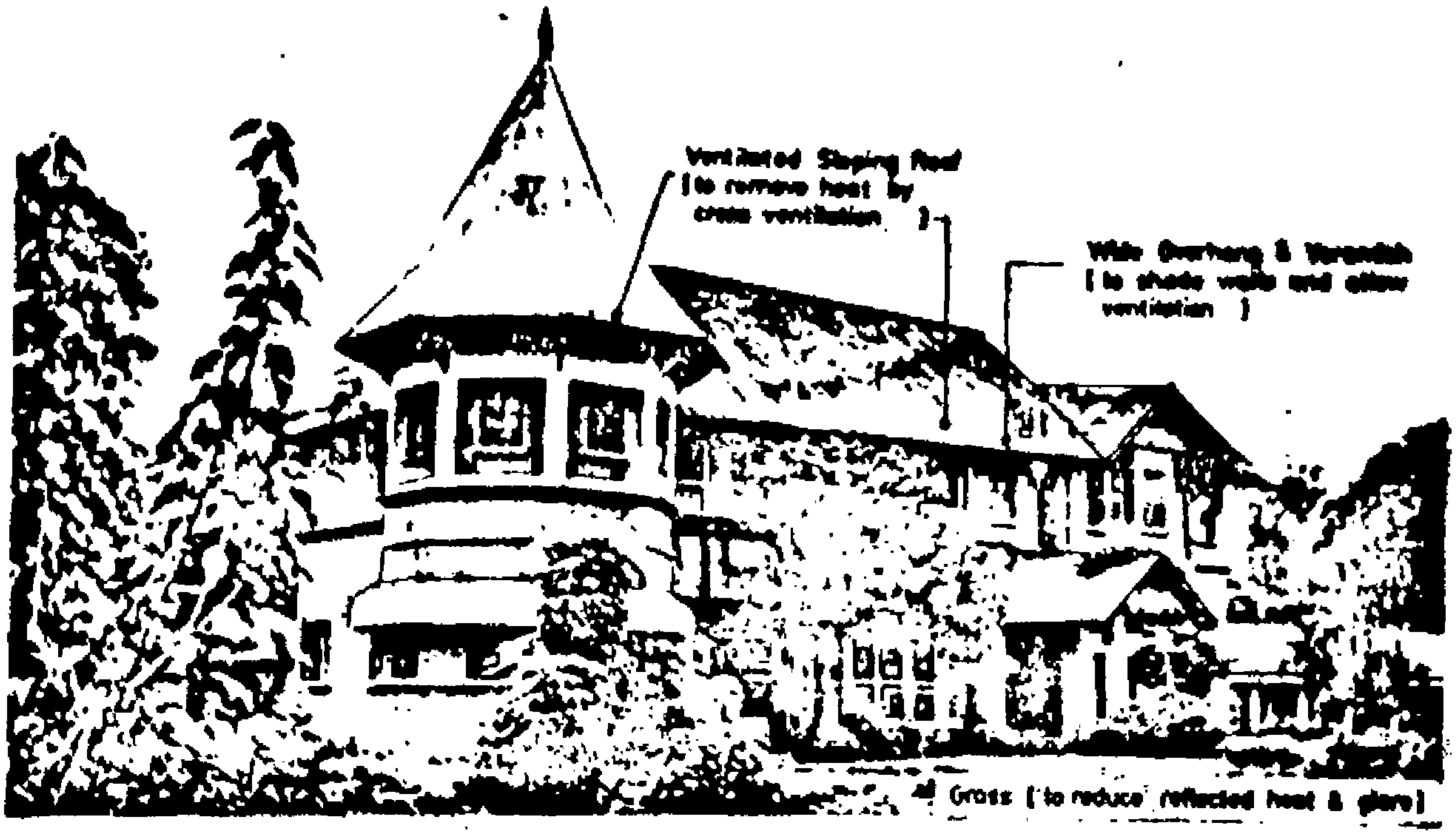


PLATE : 01 A colonial residence, making use of rural Bangladesh architectural features.

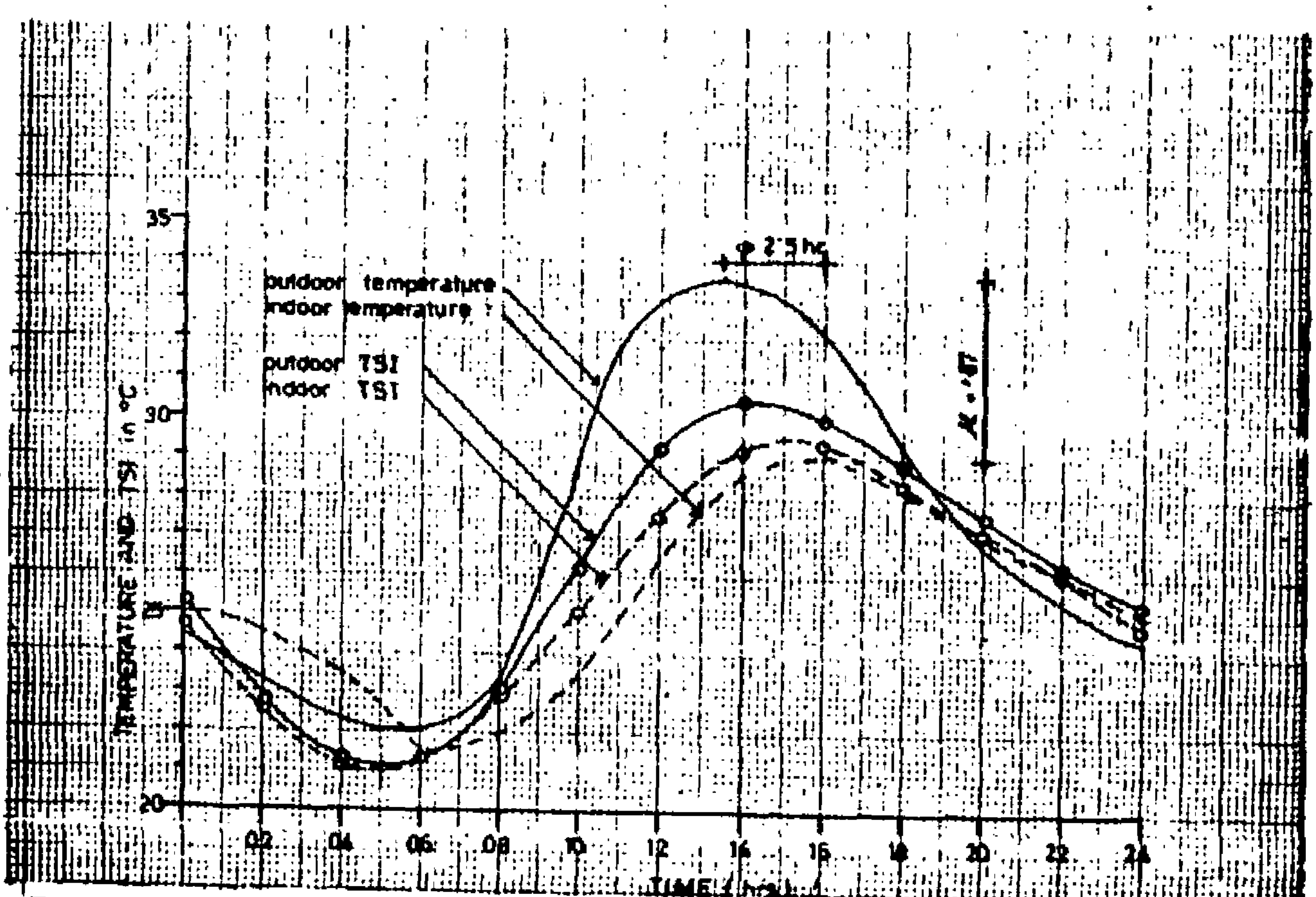


FIG : 21 Diurnal Thermal Cycle recorded on study day (author).

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NOTE : on a typical july day

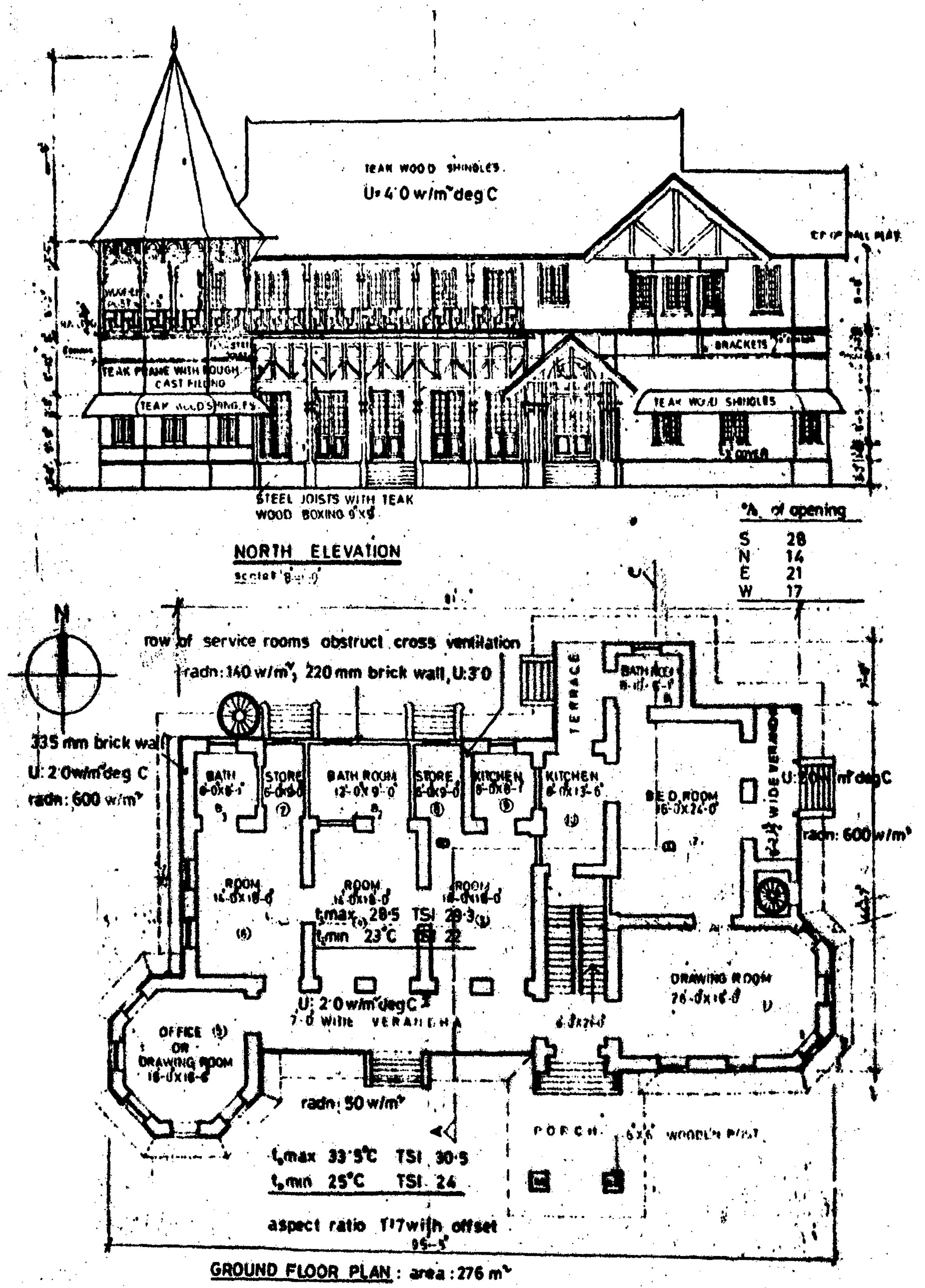


FIG:22.a Thermal performance of a Colonial residence at Dhaka [refer to plate 01. Lauther

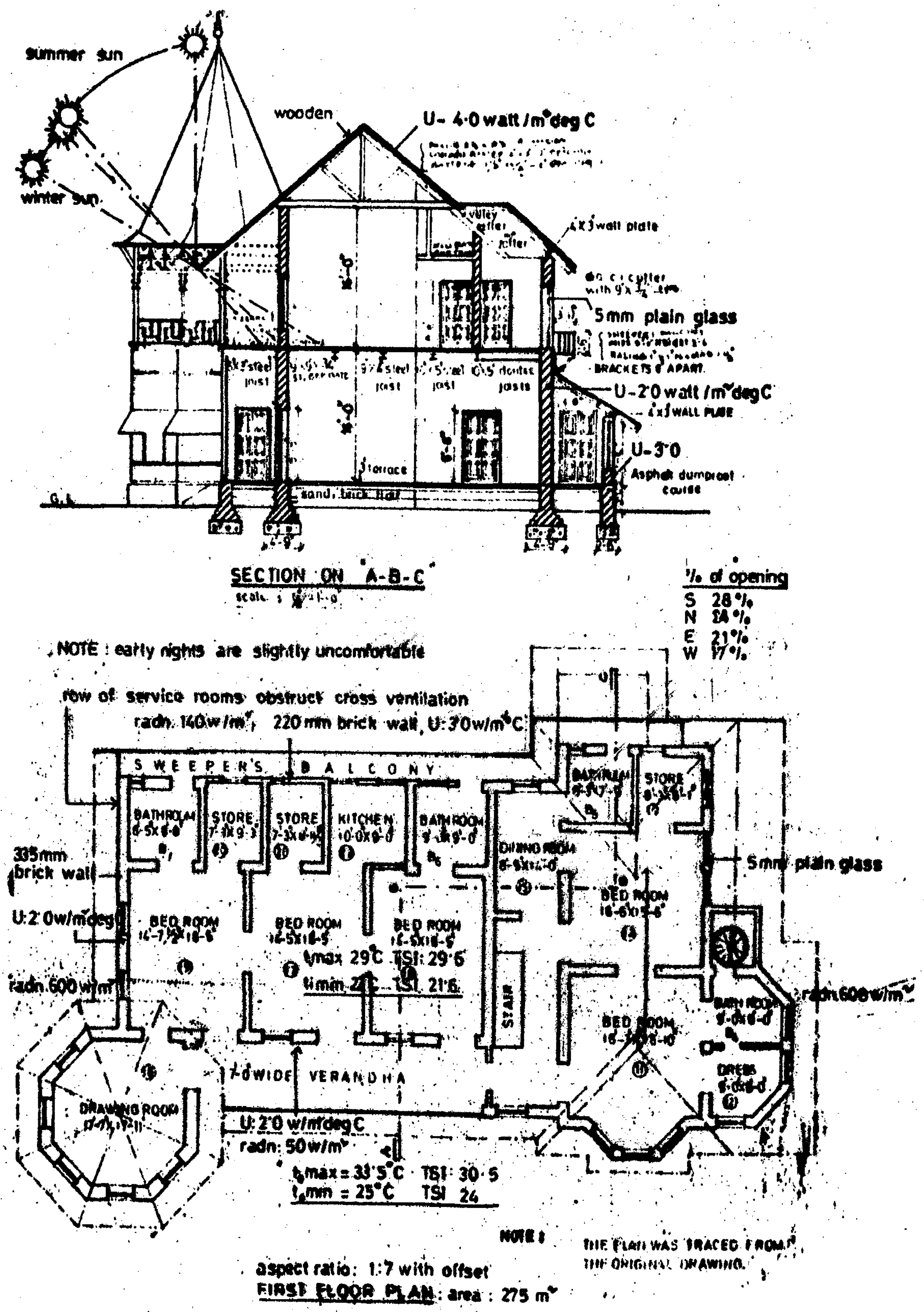


FIG:22.b Thermal performance of a Colonial residence at Dhaka [refer to plate:1]_ author.

The observations were taken on a typical July day with minimum and maximum temperatures of 25°C and 33.5°C, Relative humidity of about 87% and a typical summer wind velocity from south. A TSI range of 24-30.5°C is recorded indoors, on that particular day(Fig:21). According to inmates, early nights in summer are thermally uncomfortable, otherwise it is quite comfortable throughout the year.

Although the ventilation condition is not satisfactory due to the northern thermal buffer, yet its acceptable thermal performance greatly lies in the ideal orientation, generous and controlled shading. Uncomfortable early nights in summer may be attributed to the time-lag characteristics of the envelope, absence of exposed walls to north orientation for habitable rooms and ofcourse poor cross ventilation.

5.4 Sun control by Dhaka Art College office building:

The wing under study is the administrative block of the college, designed by architect Mazharul Islam in 60S'. It is a two storied building with art gallery and open spaces in the ground floor and common facilities and offices in the first floor. Each floor has an area of about 595 m^2(Plate:02).

Whole of the first floor southern facade of timber and glass construction has an area of 56 m^2 with 42% opening of operable glass windows. Rest 30% is timber and 28% fixed glass. Similar construction is followed in eastern and northern facades with areas of 104 m^2 and 67 m^2 respectively. In the southern facade the sun is controlled by adjustable vertical wooden louvres. Projected 180 mm thick RCC roof provides shading to all the facades. Building has an aspect ratio of 1:6.4. Most of the time in the year, no mechanical heating or cooling is required. opening and closing the windows in summer and winter respectively brings the comfort indoors. During peak summers without winds, the fans are enough. Users are satisfied with the thermal performance of the building.

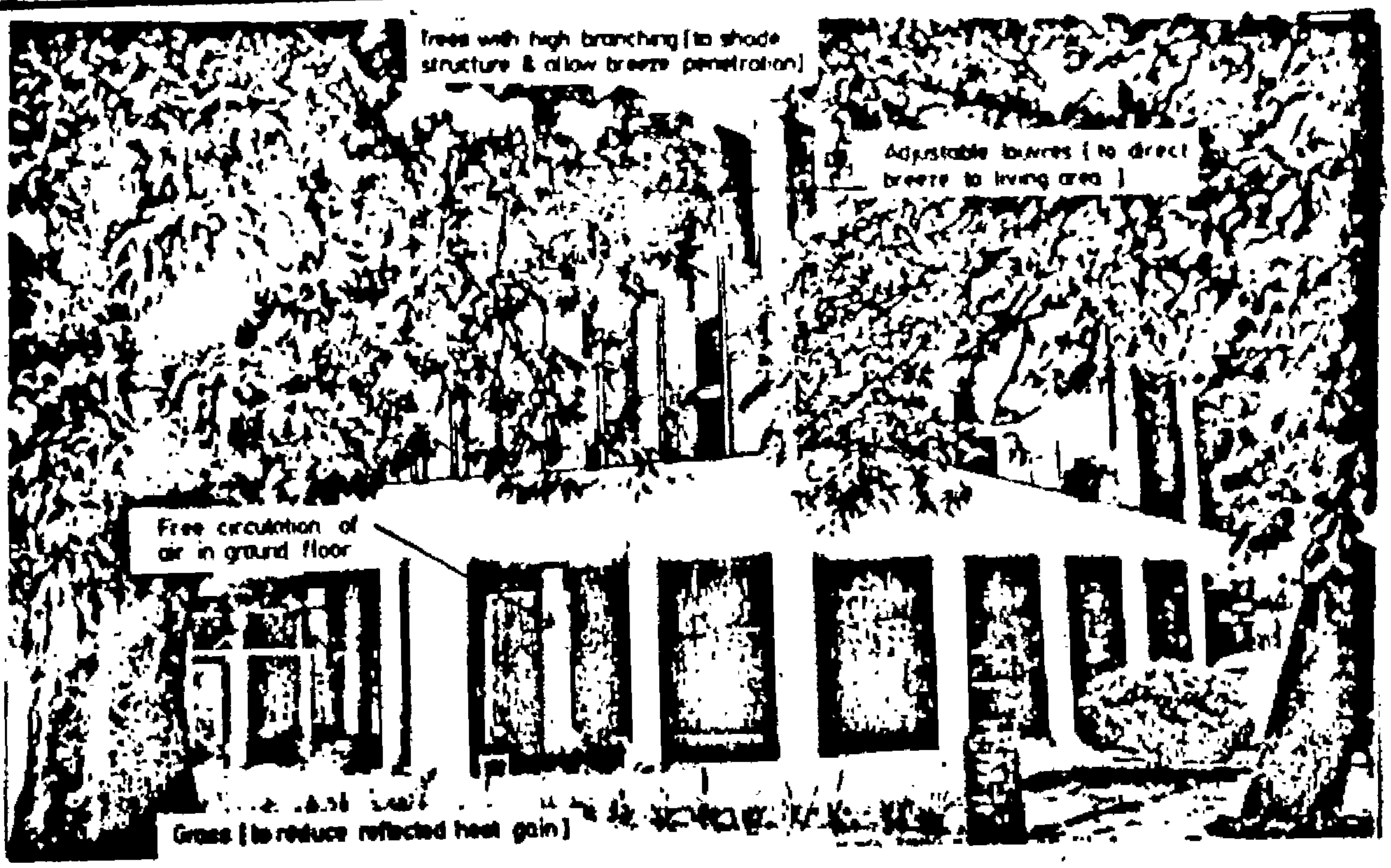


PLATE:02 Dhaka art college: adjustable louvre in the first floor and free passage of air in the ground floor.

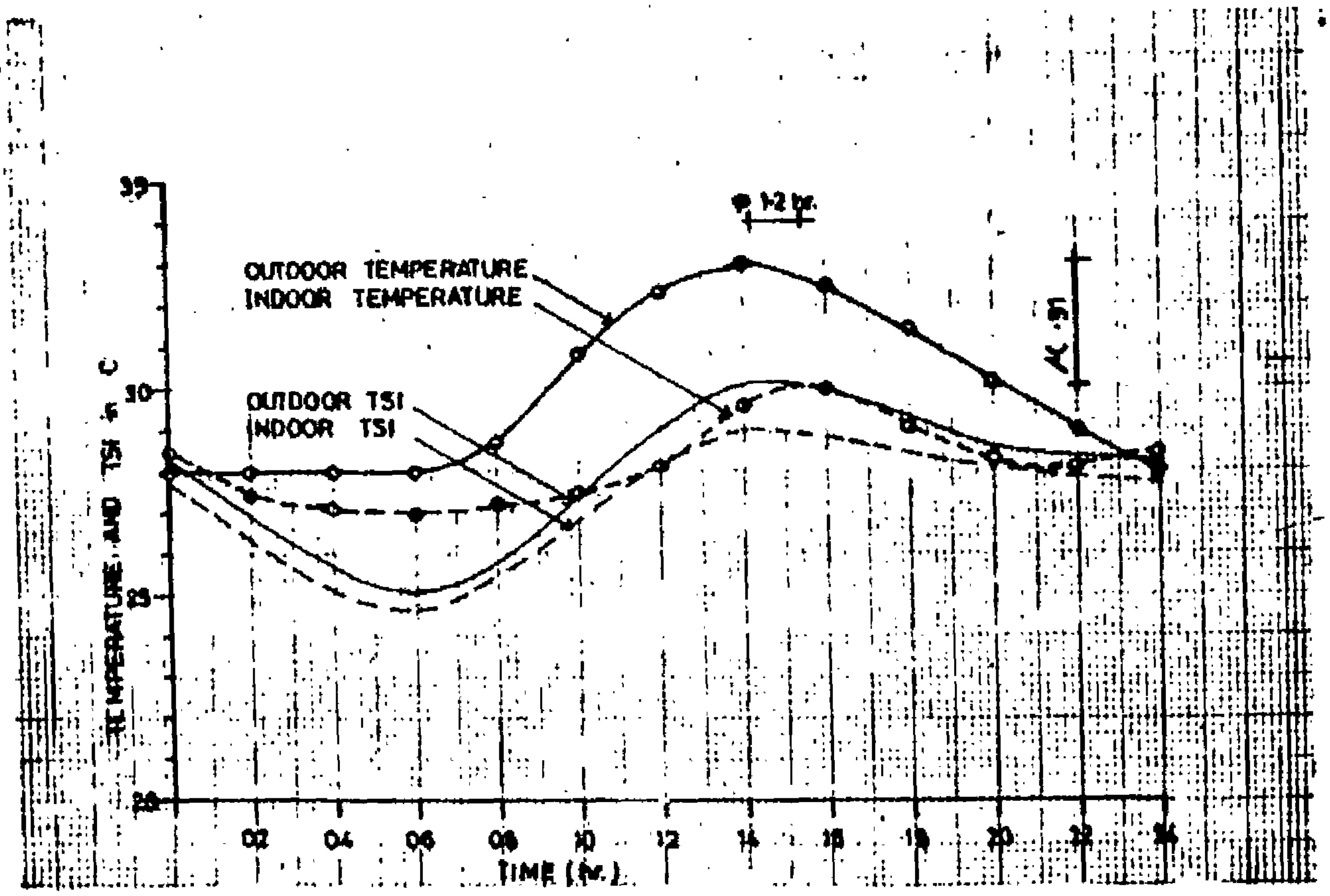


FIG:28 Diurnal Thermal Cycle recorded on study day (author)

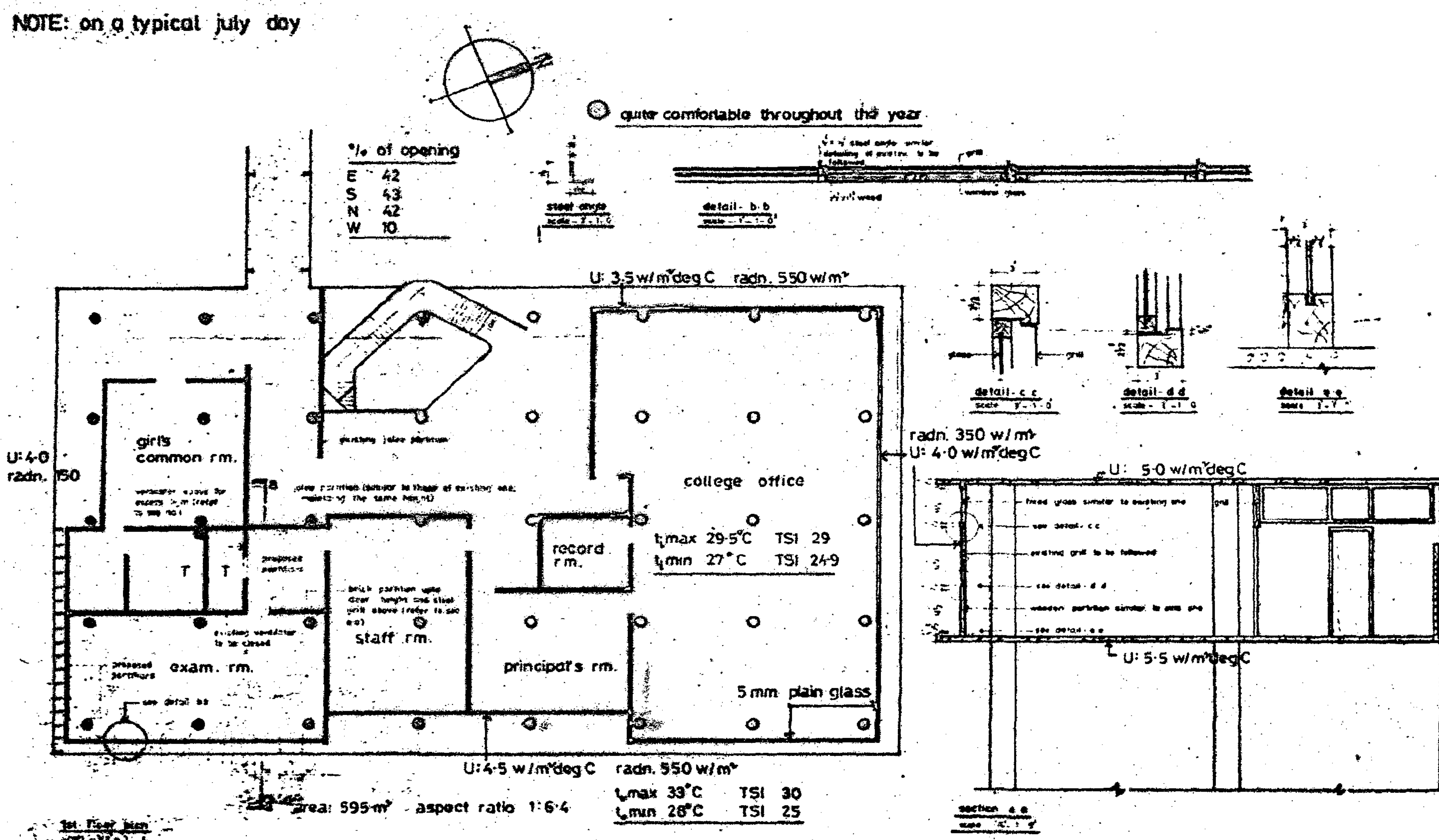


FIG 24.a Thermal performance of Dhaka Art College office [refer to plate 04.]author.

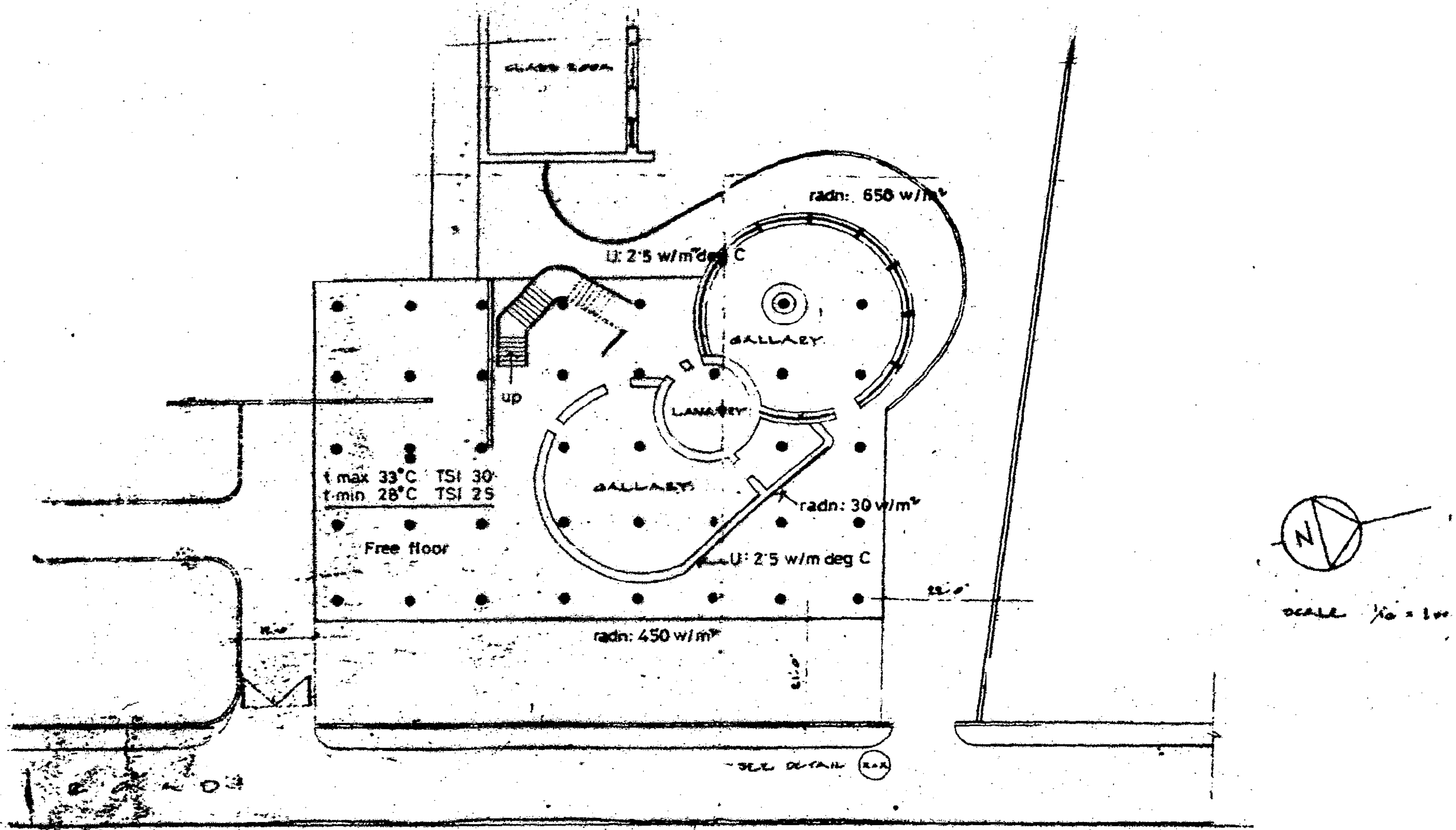


FIG: 24 .b Thermal performance of Dhaka Art College office [refer to plate 04.] author.

The study was carried out at a representative july day with minimum and maximum temperature of 28 and 33°C, a relative humidity of about 84%, and a typical summer breeze from south-east. A TSI range of 25-30°C is observed in shaded outdoors while a TSI of 24.9 - 29°C is recorded indoors with windows open (Fig:23). Thermal performance is found to be quite satisfactory inspite of unfavourable orientation. Its success probably lies in the use of light weight and low thermal capacity enclosing materials, generous adjustable shaded openings and perhaps most important of all, the control of sun in the occupied zone (Fig:24 ,).

5.5. Performance of some of the other buildings surveyed (subjective):

Plates 03 to 10 shows glimpses of a few more, climate effecient buildings with special architectural elements, making use of traditional concepts and modern techniques for better thermal performance of buildings. Some of them were studied subjectively and the findings are given below.

a. Teacher-Student Centre (D.U.), designed by Doxiadis associates is not a solar building but a contemporary design on climatological basis (Plate:06) which includes a responsive mechanism for the absorption or rejection of solar radiation. Reflectivesouth and north facades with more than 50 % shaded opening and shaded roof perform well, both in summer and winter. Temperature can be maintained as low as 25°C without fan but mechanical ventilation is required to remove stricky conditions.

b. Home-economies College (HEC) - multipurpose hall and administration building (Plate:7, 8) both designed by Doxiadis associates are performing well for over 20 years almost without any

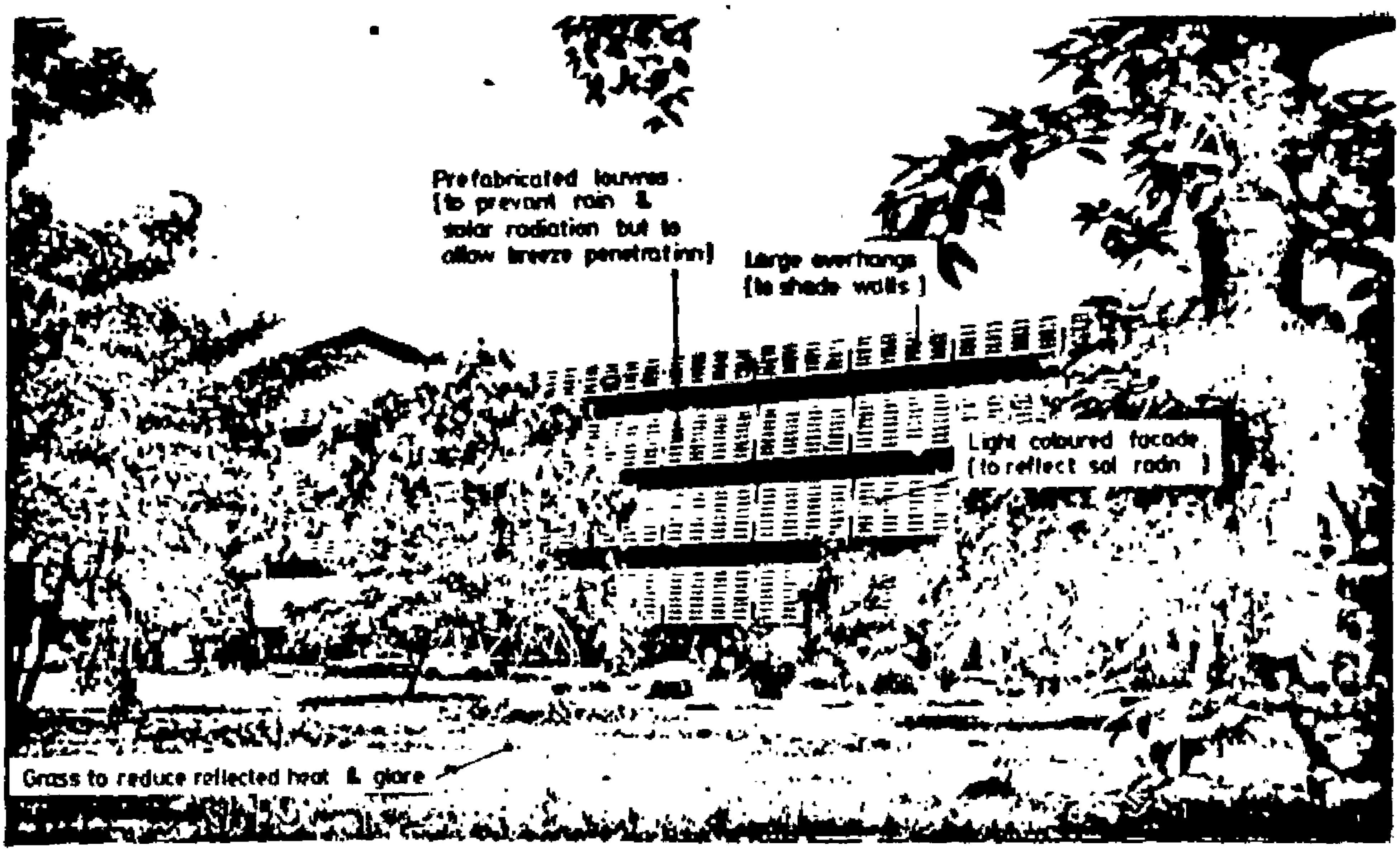


PLATE : 03 Architecture building [BUET, Dhaka], multipurpose shading devices that prevents rain & solar radiation but allows maximum ventilation in the building.

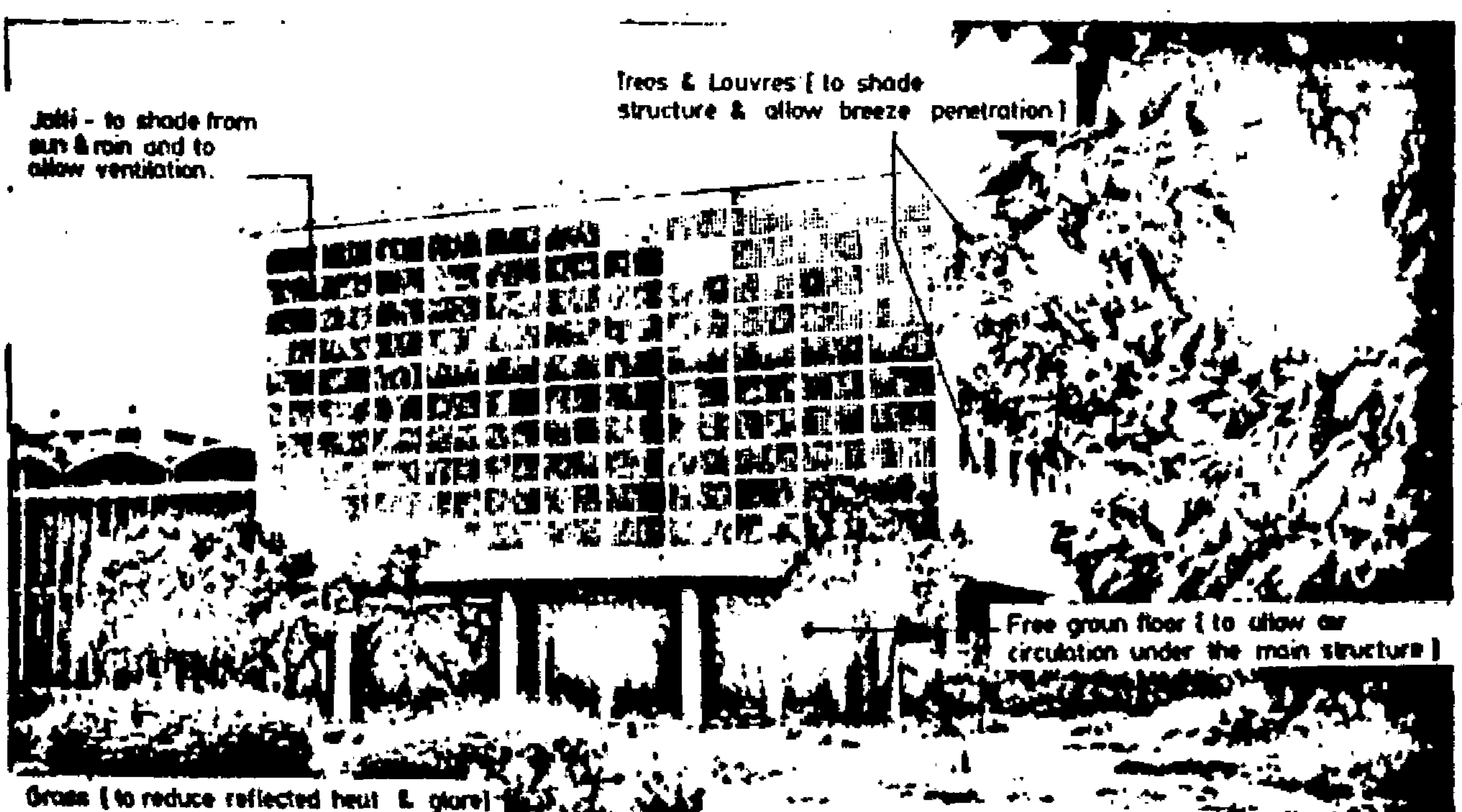


PLATE : 04 Library building [D.U] , using 'jalli' in the east & west facade, and adjustable louvers on the south & north.

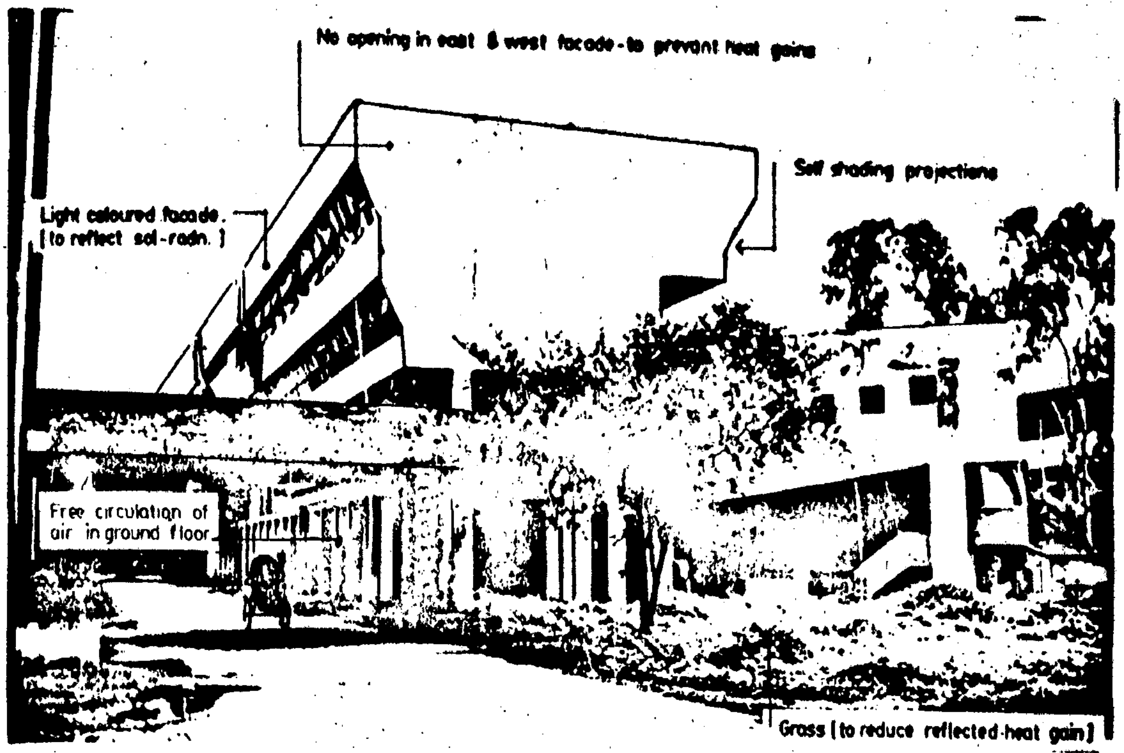


PLATE: 05 A building of dhaka university with self shading projections.

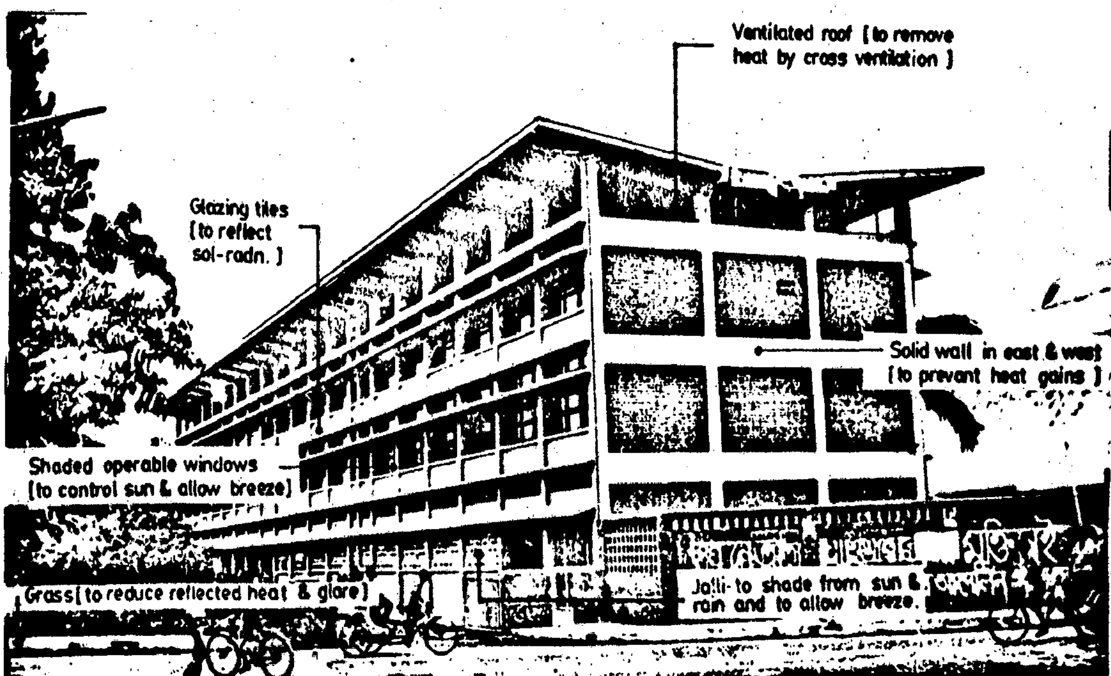


PLATE: 06 Teacher-student centre [D.U], making use of shaded roof and reflecting facade with shaded windows.

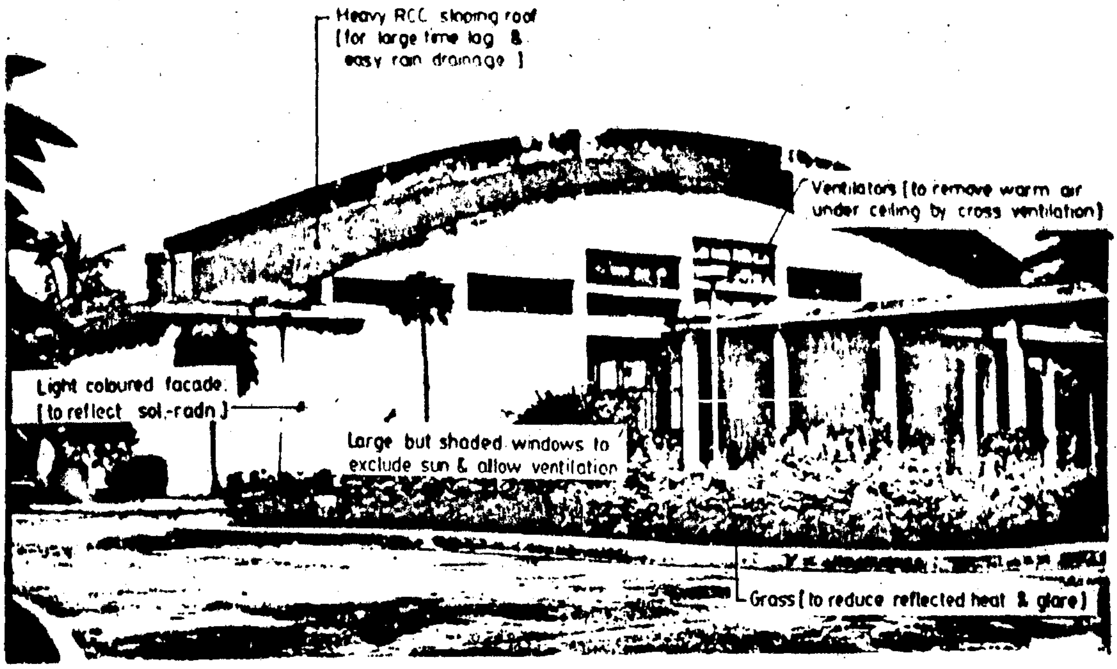


PLATE: 07 HEC - multipurpose hall, using thermally efficient roof and operable windows.

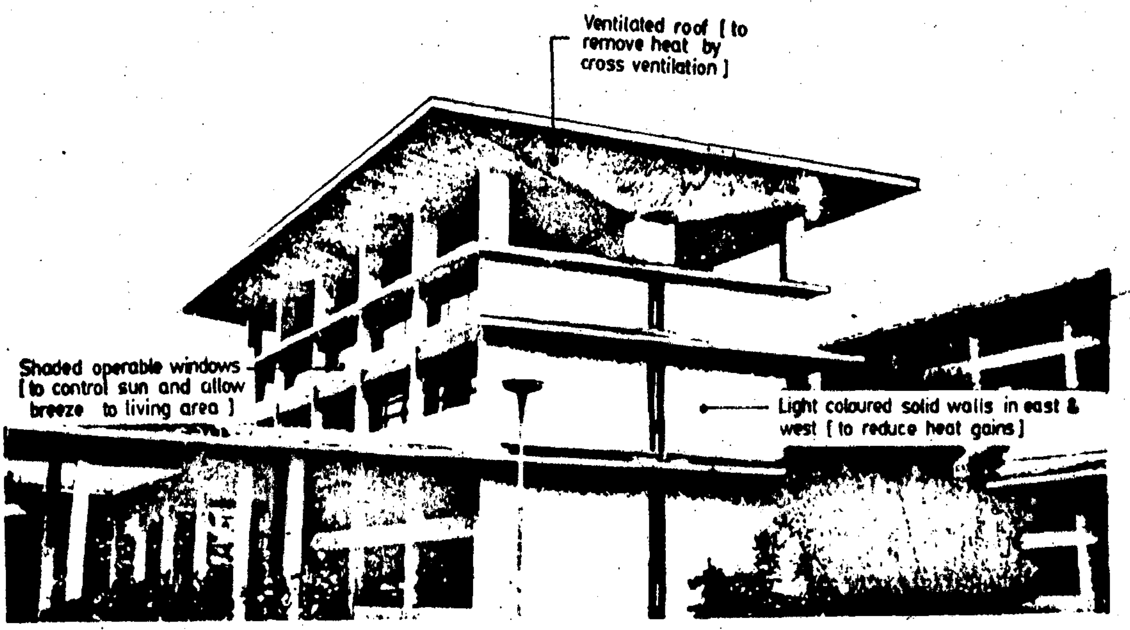


PLATE: 08 HEC - administration building having shaded roof and windows.

auxilary heating and cooling. Approximately the following temperature have been maintained. Nov-Feb (14°C-20°C), Feb-April (18°C-22°C), April-July (24°C-30°C) and July-Nov.(20°C-25°C) Users are satisfied with the thermal performance of the buildings.

HEC-multipurpose hall(Plate:7) is a single storey block with 1.5 times normal height with north and south facade having more than 50% operable glass openings, which can trap heat in winter and ensures cross ventilation in summer. The 180 mm domical pitched RCC roof and 225 mm thick east and west white washed solid walls perform adequately.

HEC-administration building(Plate:8) is a R.C.C. frame construction with brick walls, outer north-south skin is more than 50% glass window having outer shade and moveable inner curtains. 225 mm brick wall and 180 mm R.C.C shaded roof, performs well thermally.

c. Residential buildings in Sher-e-Bangla Nagar (Dhaka): We witness a great feat of contemporary architecture in its purest form at sher-e-Bangla nagar(Dhaka) designed by Prof. Luis I Kahn.

The residential buildings(Plate 10) were designed to utilize natural forces to achieve maximum internal thermal comfort. He used the concept of traping the sun by solid wall in the eastern and western walls (with only windows in toilets) and manipulating the summer and winter sun by large operable glass doors and windows in south and north, which also gives rise to a very effacient cross ventilation.

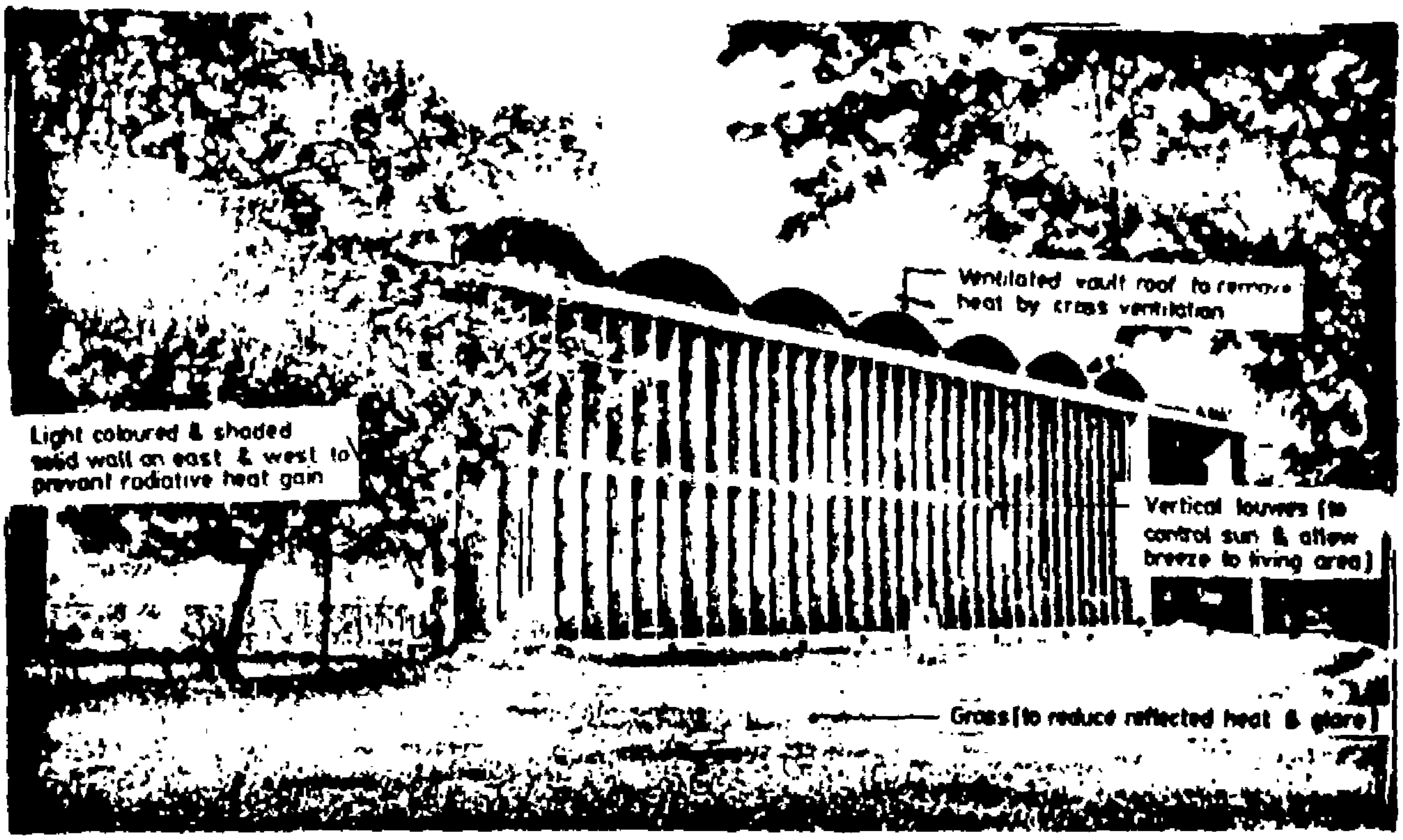


PLATE: 09 Library annex [DU] with vault roof and louvred facade.

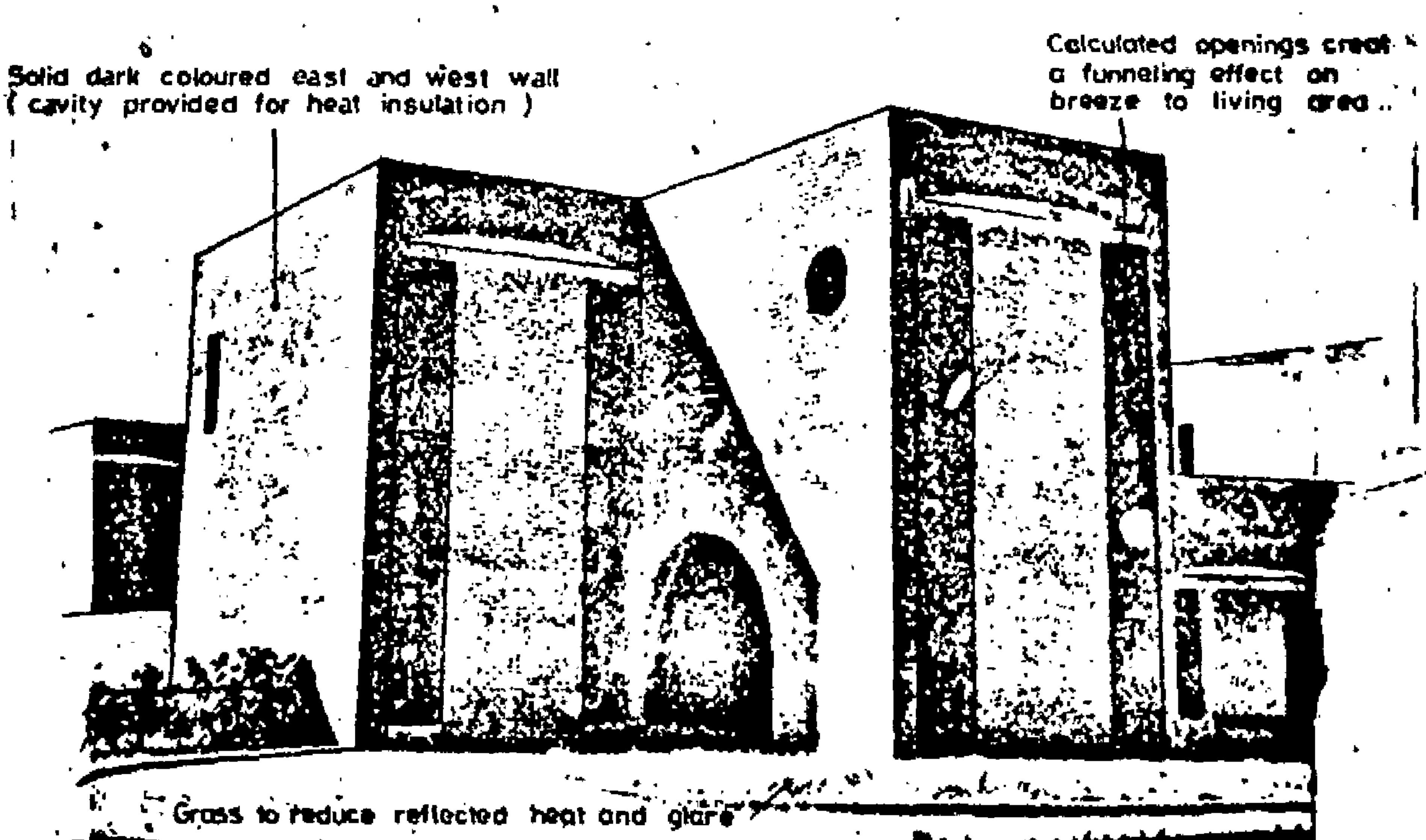
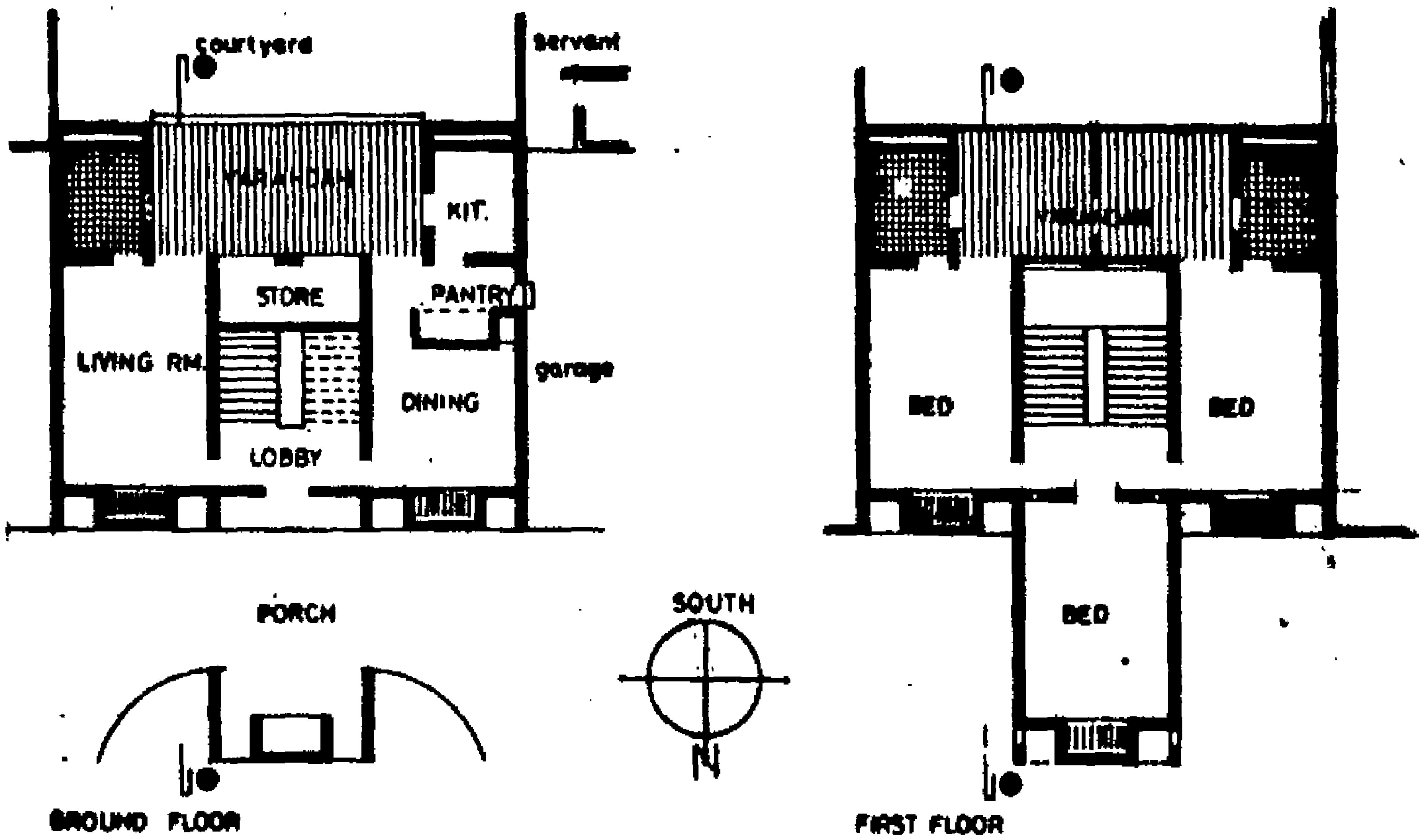
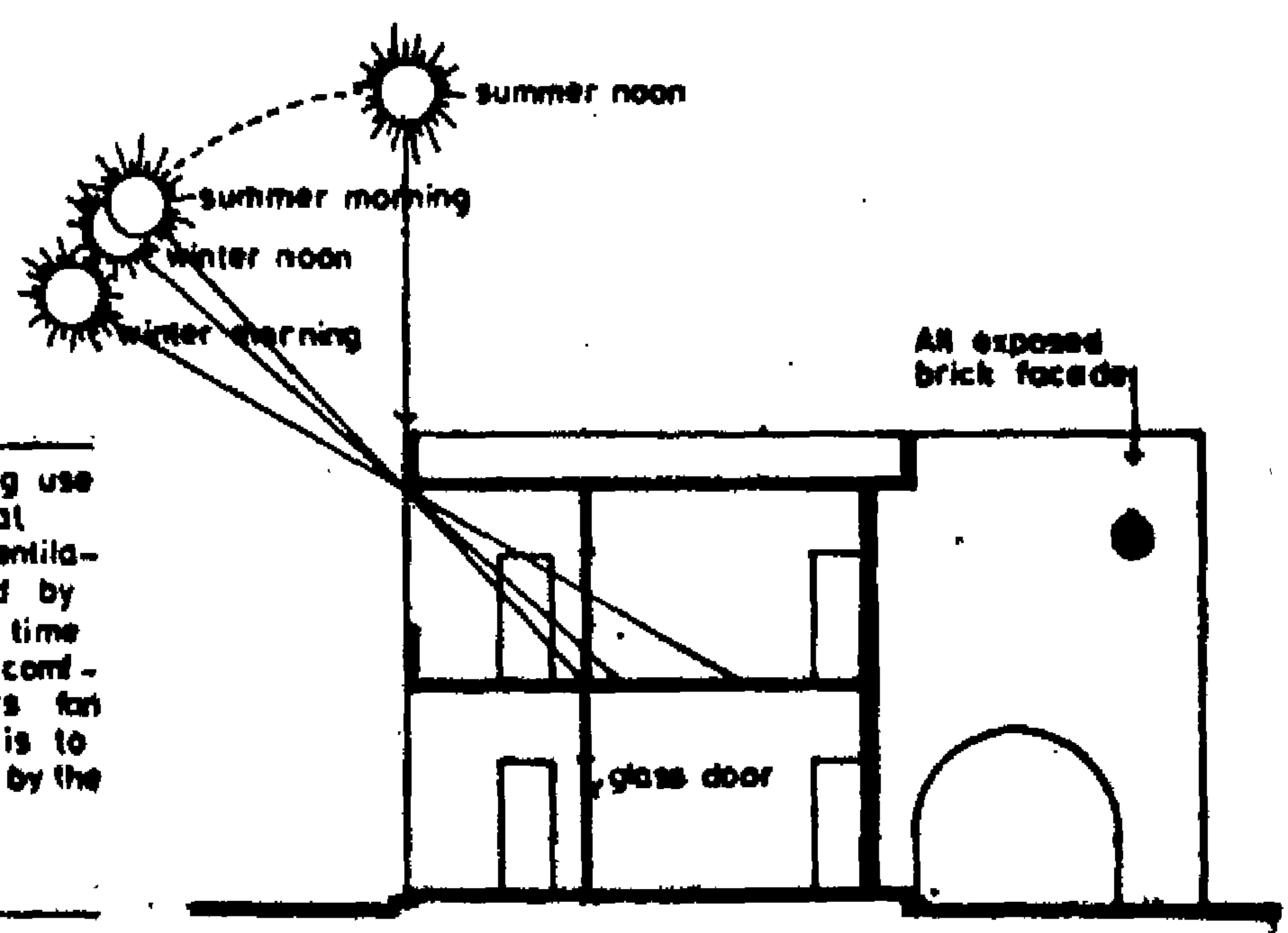


PLATE: 10 B-type residential building, sher-e-banglanagar, dhaka



For over last 15 years, the following temperatures have been maintained :

—	march april	18 – 24 C
—	may august	20 – 27 C
—	sept. oct.	17 – 21 C
—	nov. fab.	15 – 18 C



PERFORMANCE

Complete passive system, making use of seasonal solar angles, thermal property of material & cross ventilation. East & west walls shaded by adjecent buildings. Most of the time in the year TSI remains within comfort range. During peak summers fan is required and in winter wind is to be restricted. Sun is controlled by the design.

FIG: 25 Thermal performance of B-type residential building, SBN, Dhaka. (author).

Although Kahn selected red ceramic brick and R.C.C as his basic materials which is not recommended by experts for warm humid places, yet by his judicious design and appropriate construction detailings he made these dwellings thermally very effecient(Fig:25).

Author stayed in one of these dwellings for long six years and observed that only in extreme hot months (May-July) a negligible active aid is required for cooling the indoors and for remaining months interior environment is quite pleasent. Ineffecient direct rain control is the main drawback of design.

5.6 Summary of discussion

a. In warm-humid regions, like of Dhaka, the adverse heat impact of sun from east and west ends of a house, force it into an elongated low rise structure. This shape would also provide advantage of baneficial wind effect under high vapour pressure. Volume effect of building shape is not much significant in warm humid regions.

b. Review of vernacular architecture, reveals that openness, shading and low thermal capacity building enclosure is the characteristic feature of architecture in Dhaka. It is also seen that the vernacular methods of achieving comfort is employed successfully in its urban architecture but requires further optimization.

c. Thermo-physical properties of the enclosing material does not effect much to the inddor thermal comfort. But it is observed in general that light weight and low thermal capacity material contributes more to the comfort condition indoor.

d. Though for total control of comfort conditions, each of the influencing climatic element like solar radiation, sun light, wind, relative humidity, rain etc. must be fully controlled yet it is observed in the foregoing studies that near comfort conditions can be arrived by effecient sun control design and following the general design criterion for warm humid regions. It is also observed that by an effecient sun control design, rain factor is automatically taken care of to a large extent.

e. An ideal building for Dhaka is, therefore, a south oriented rectangular, single room deep plan with more than 30% opening in each wall facing windward and leeward sides for cross ventilation. The construction material is normally brick with or without cement plaster in outer face.

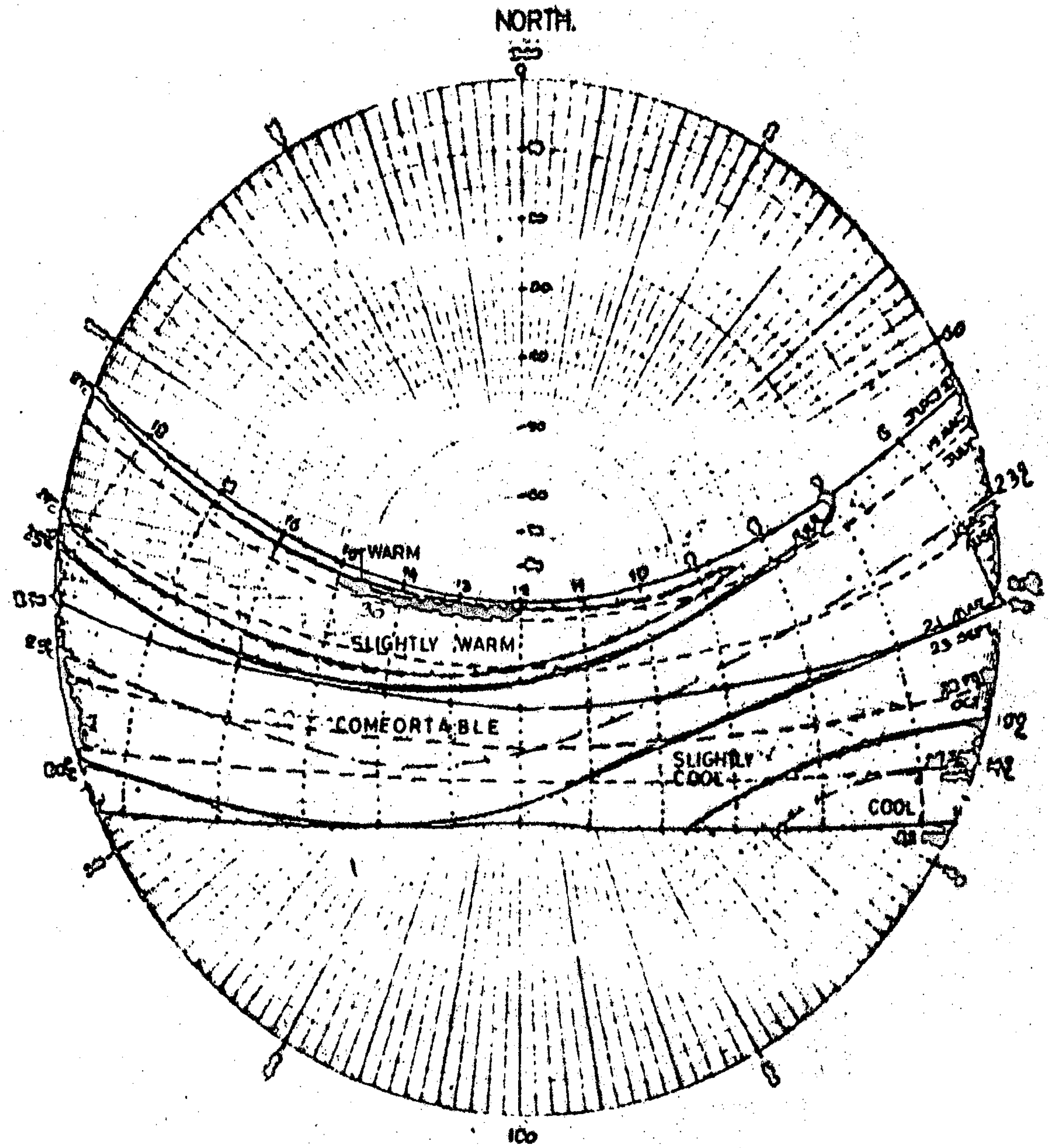
6.0 ANALYSIS OF SUN-BUILDING INTERACTION FOR DHAKA (BANGLADESH): $23^{\circ}45'$N AND 90°E

6.1 Enumeration of desired form performance relationship:

In order to investigate the sun-building relationship it is necessary to specify days of the year and the times of the days with reference to which thermal control (i.e. solar irradiation) and shading effects are to be investigated. For the present study it is considered sufficient to use the two extreme days of summer and winter salstices, namely June-22 and December-22 respectively and the equinox i.e. March-21 and September-23. Also it is thought convinient and appropriate to refer the solar data to the three instants of the days, namely the mid-morning (8:30a.m. in summer, 9.15a.m in winter), the mid-day (12:0 noon), and the mid afternoon (2:30p.m. in summer, 2:45p.m. in winter).

With the computed solar data for Dhaka, found out by the equations 03 and 04, two sun path diagrams are made (Fig:26,27) to read sun-building interactions, with the help of shadow angle protractor, solar radiation protractor(29) and total heat gain protractor (Fig:28) for vertical single glazing(34). The analysed data can be cross checked by the mathematical equations, 05 to 28, presented in artical 2.1. The results thus computed, represent any typical case encountered with respect to sun-building interaction for Dhaka.

Although it is not possible to increase the incident solar radiation on a surface during winter, it is always possible to reduce it in summer by the use of shading devices by choosing optimum orientations and selecting appropriate materials for envelope(39). It is seen from the sun path diagram (Fig:26) that the sun does not shine directly on the northern facade, except during early morning or late afternoons in summer. The investigation is carried out under



Effective temperature (ET) ploted over sun path diagram to see the the thermal conditions at Dhaka (the result is not satisfactory).

FIG:26. Sun path diagram ploted for Dhaka: 23°45'N (author)

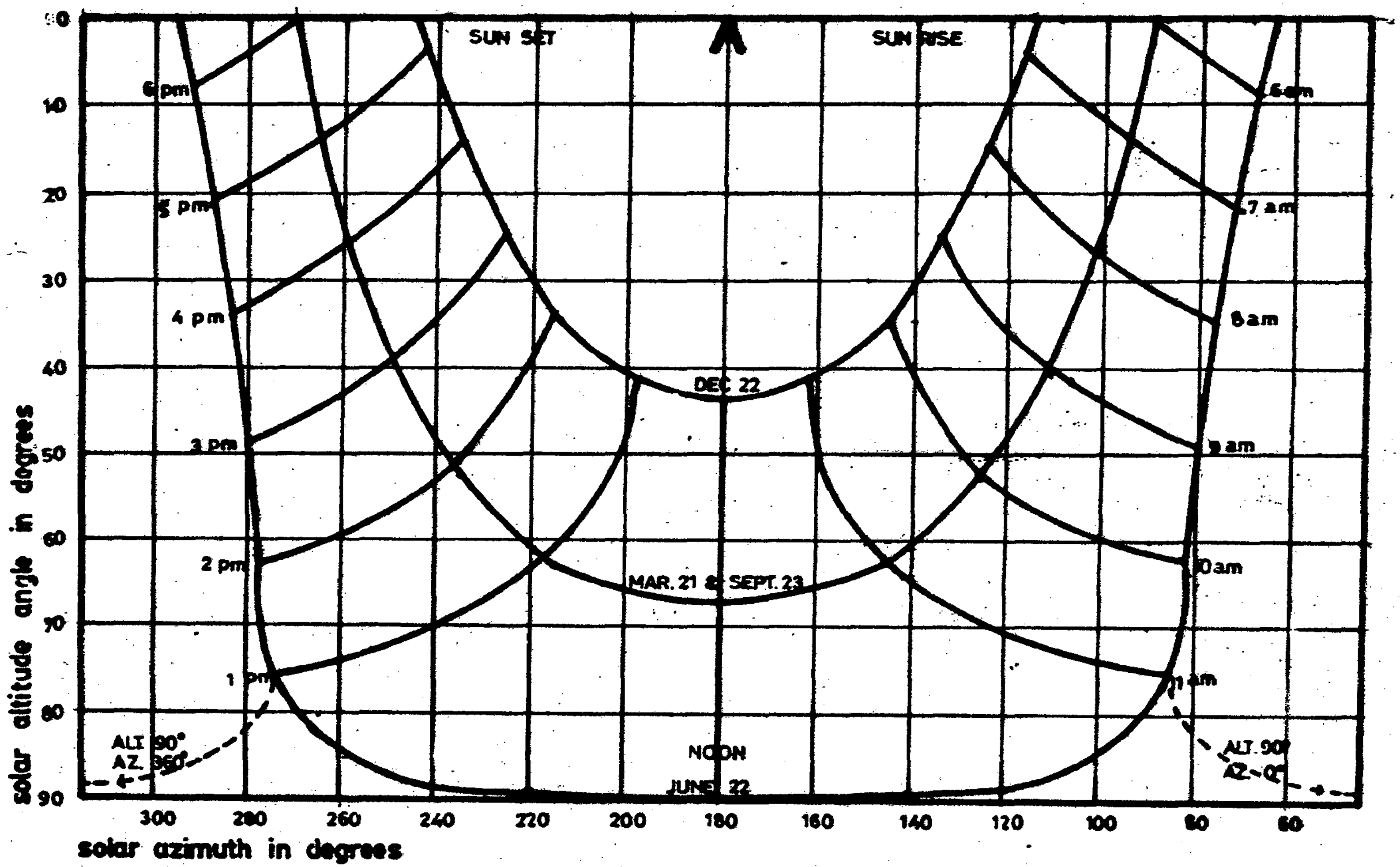


FIG. 27. SUN PATH DIAGRAM FOR DHAKA [LAT. 23°46'] (author)

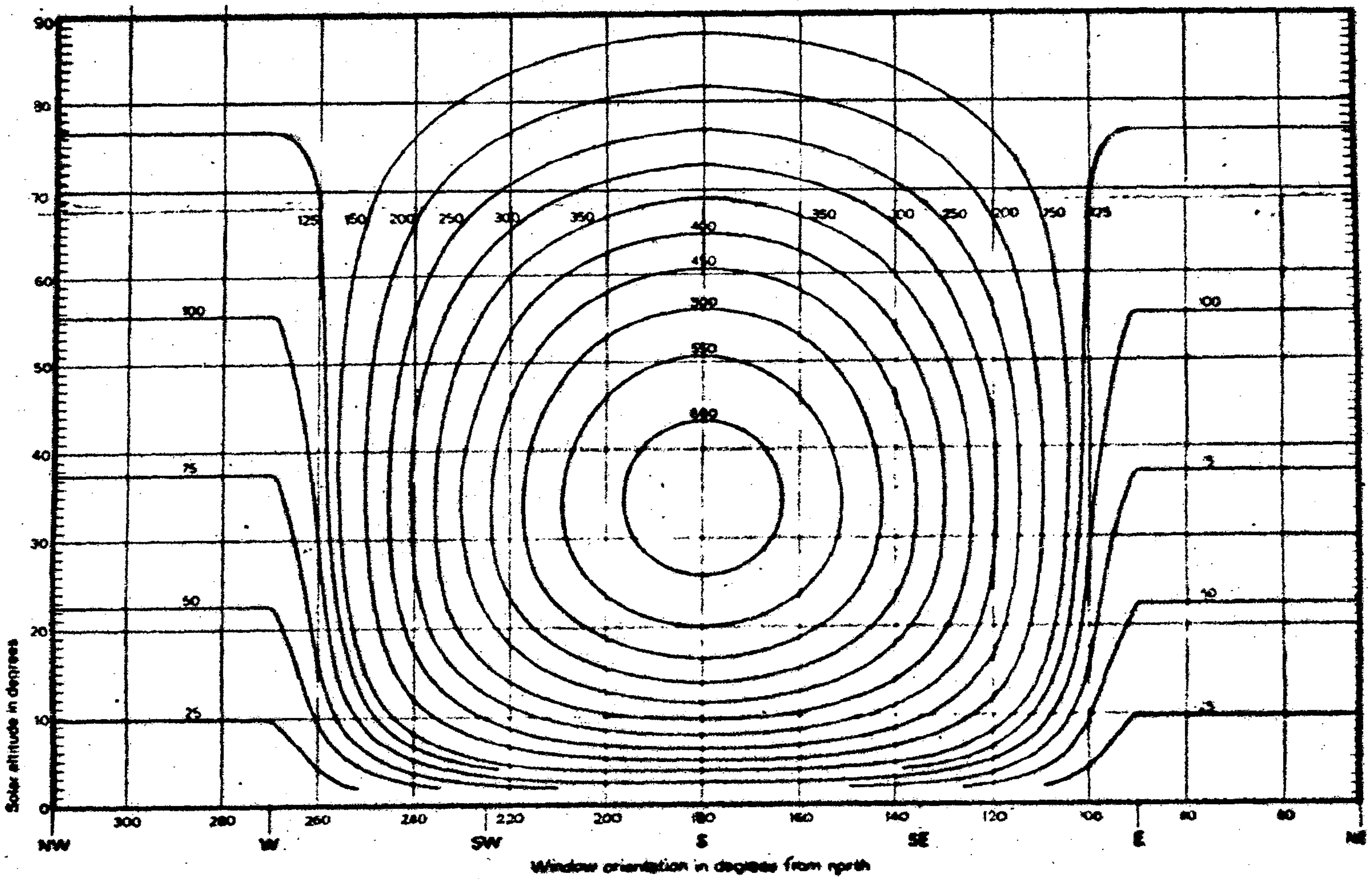


FIG.28 TOTAL INSTANTANEOUS HEAT GAIN THROUGH VERTICAL SINGLE GLAZING IN W/m^2

(Pilkington Brothers graph extended by the author for Dhaka) the following heads:

- Solar radiation pattern on buildings.
- Sun light pattern in built form.
- Solar heat transfer into the building.

6.2 Solar radiation pattern on building

Duration and intensity of solar radiation received on the facade is studied for the variation in the angle of orientation of the surface as follows:

6.2.1 Duration of solar radiation received on the fecade vs - variation in the angle of orientation of the facade: This relationship is investigated by using the sun path diagram and shadow angle protractor. The protractor is placed on the sun path diagram with the centre of the base line coinciding with the centre of the sun path diagram and the surface orientation' line set in the direction of orientation of the plane. The duration of solar radiation received on the facade is given by the uninterupted length of sun path or the intersect portion of the sun path between the base line of the protractor and the eastern or western peripheries of the diagram and result tabulated as shown in appendix-7 and graphically presented in Fig:29 to facilitate reading for any instants of the day and orientation of the facade.

6.2.2 Intensity of solar radiation received on the surface - vs - variation in the angle of orientation of the facade: This relationship is studied by using sun path diagram and the total radiation protractors' for vertical surfaces. Procedure is similar to that of art. 6.2.1., the values of the direct and diffused components of solar radiation on the plane at the required instants of the days are read from the points on the direct and diffused equiradiation contours on the protractor. The result is tabulated in appendix -8 and is graphically presented in Fig:30 for

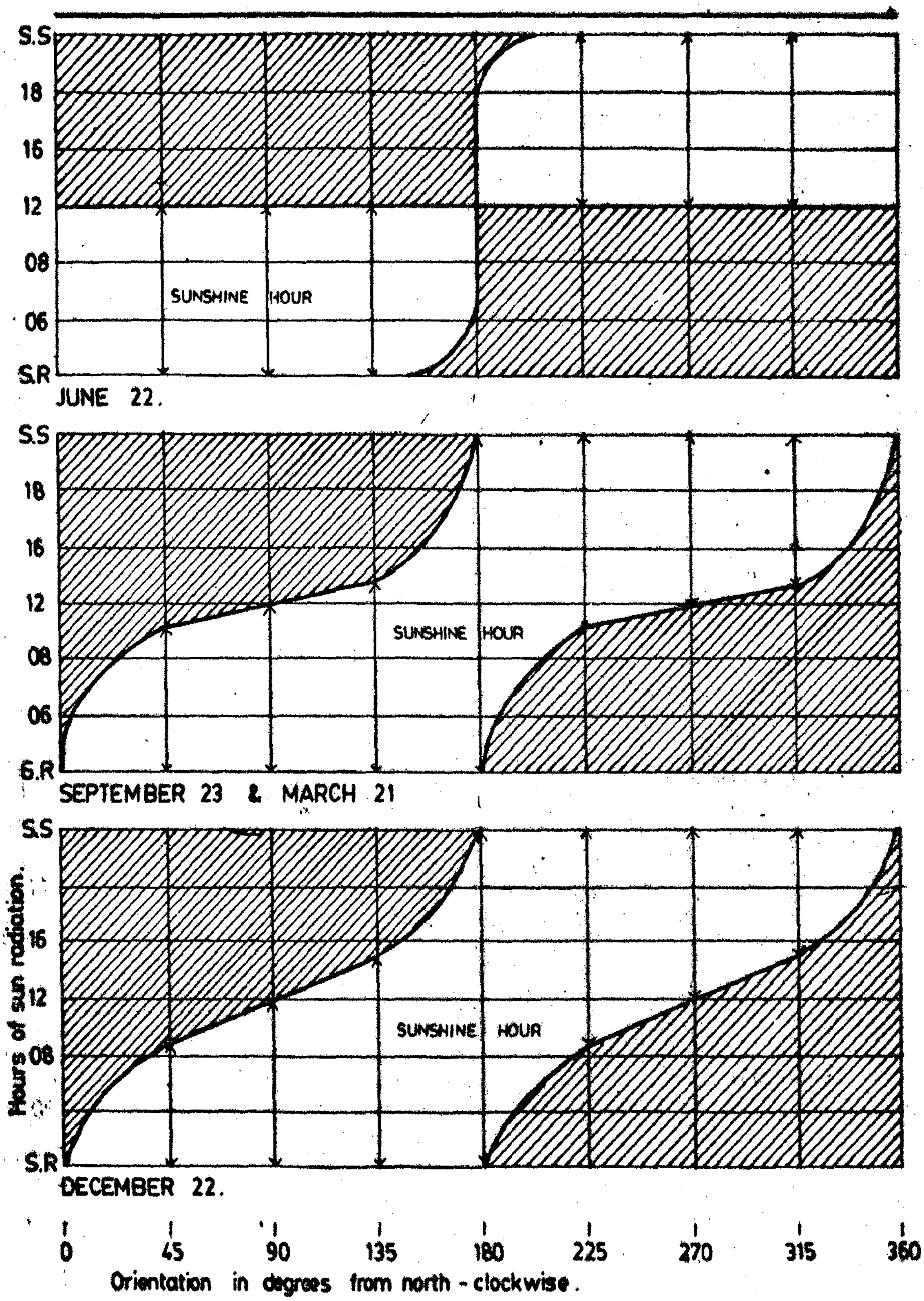


FIG: 29. Duration of Solar Radiation Received on the Facade (appendix - 7). author

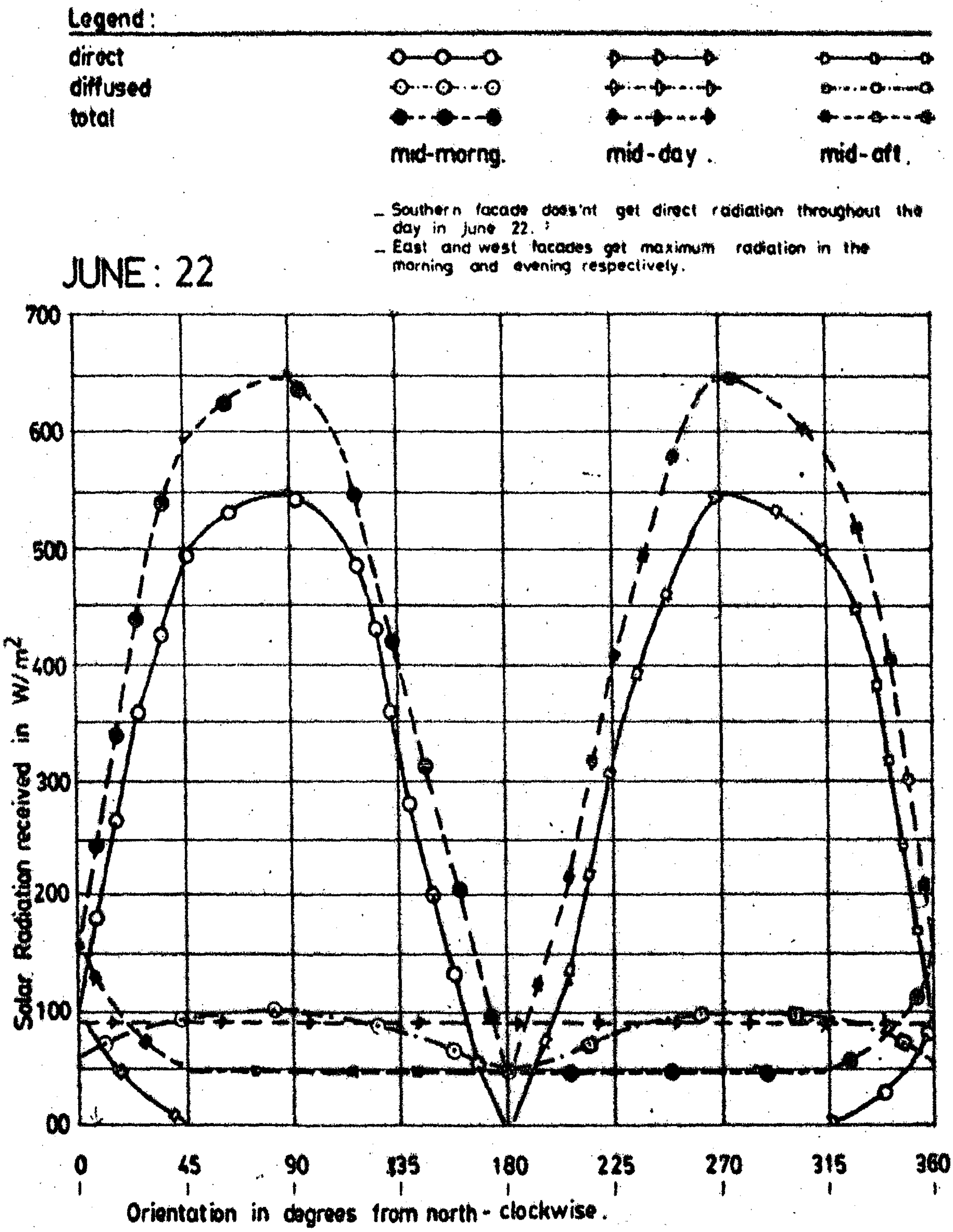


FIG:30·1. Intensity of Solar Radiation Received on the Facade (appendix - 6).author

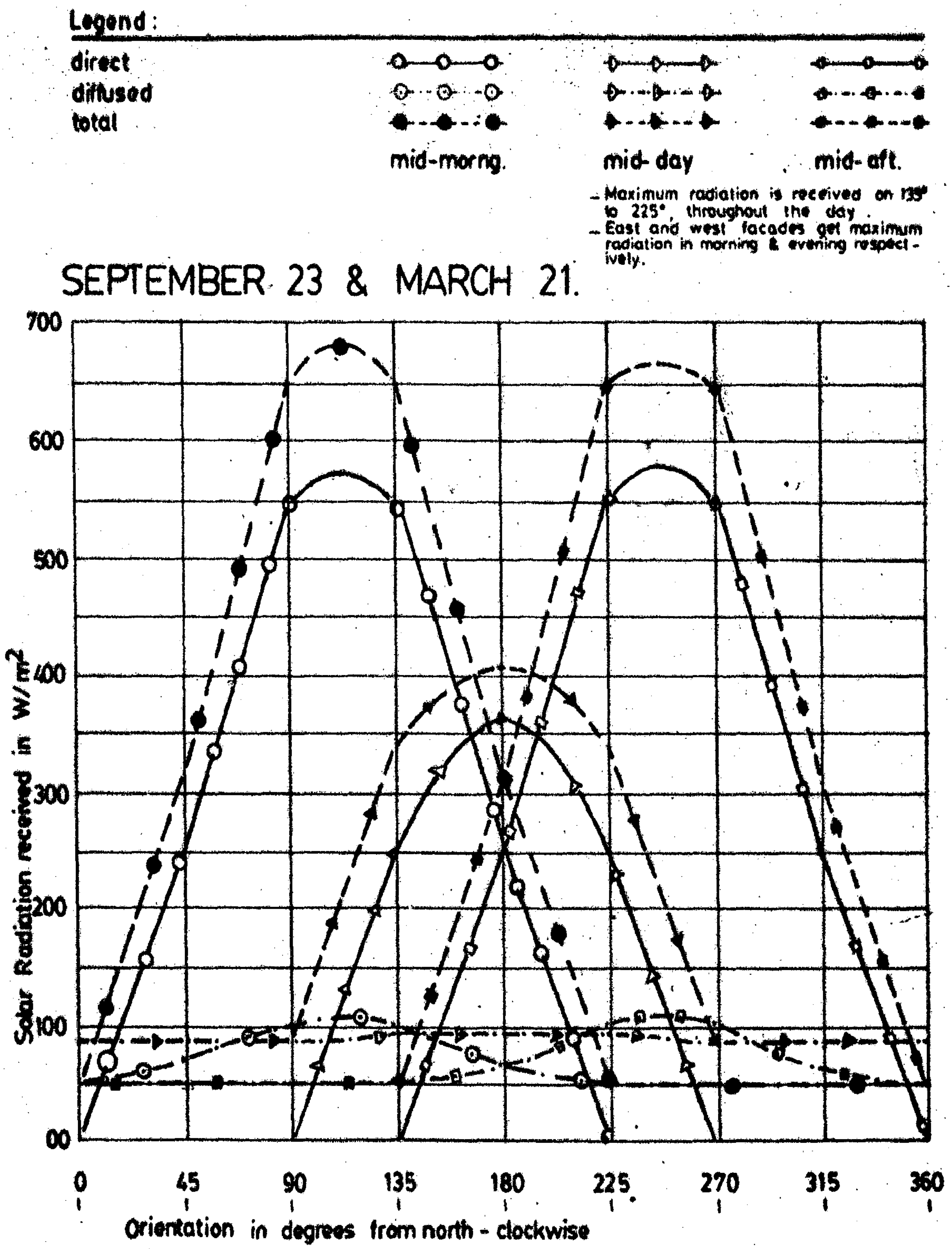


FIG: 30·2 Intensity of Solar Radiation Received on the Facade (appendix - 8)_author

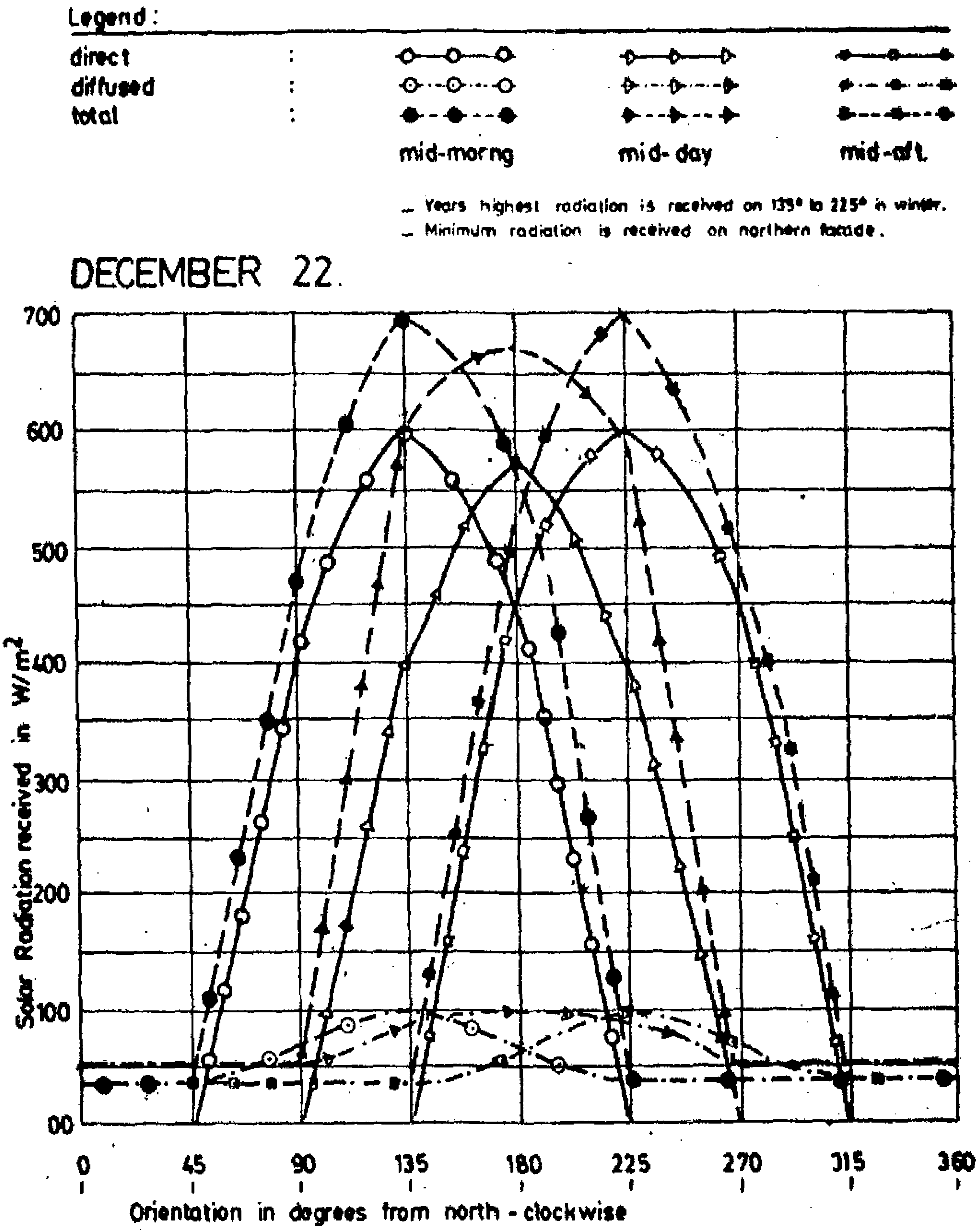


FIG:30·3. Intensity of Solar Radiation Received on the Facade (appendix - 8).author better understanding. For a comparison, Sharma's(48) computation for Calcutta may be refered.

6.3 Sun-light pattern in built form:

It is a good practice to be able to predetermine the thermal performance of a proposed built form with special reference to the availability of sun shine inside rooms or varandah during winter and its exclusion during summer(39). An exact delineation of the sun light pattern require mathematical calculations. Sharma(46) used shadow chart for sun light penetration indoors. Following investigation gives mathematical-cum-graphical method for easy assessment of pattern.

6.3.1 Degree of coverage of the indoor space by the penetrated beam of sun light (width and depth)- vs - variation in the width and height of the opening and the angle of orientation of the facade:

From the Fig 31, the relationship is investigated. Let, h-be the height of the opening on the facade, w- be the width of the opening on the facade, d-be the depth(horizontal projected) of the penetrated beam of sun light, and W-be the width of the penetrated beam of sunlight. Than

$$d = h.\cot \alpha \qquad 38$$

and $$W = w.\cos \theta \qquad 39$$

where α= Vertical shadow angle with respect to the plane of the opening.

θ = Horizontal shadow angle with respect to the plane of the opening.

Value of α and θ will be different at different instants of the days and for different orientation of the facade. Therefore, values of α and θ and also $\cot \alpha$ and $\cos \theta$ need to be computed in relation to variation in

Legend:

mid-morning	:			
mid-day	:			
mid-afternoon	:			
		june 22	sept.23 & mar.21	dec. 22.

$$d = h.\cot.\alpha \quad \& \quad W = w.\cos.\theta.$$

- Deepest light penetrates in winter ie. 1·73 times the height of opening in 135°-225°S
- Widest light penetrates in winter ie. equal to width of opening in south orientation.

Note: refer to fig: for 'h' & 'd'.

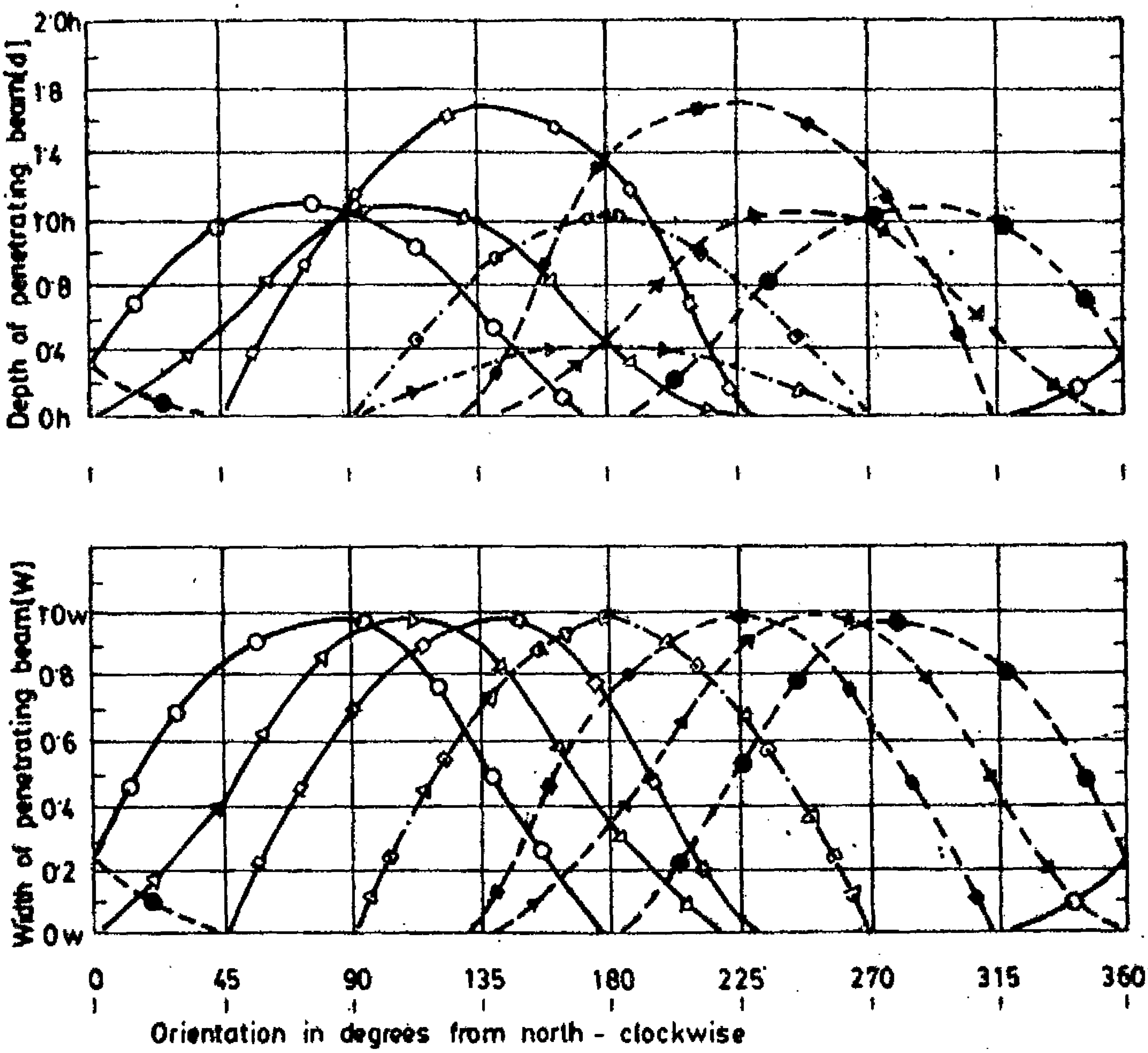


FIG: 32 Coverage of Indoor Space by Penetrated Sun beam (appendix- 9)_ author orientation of the facade. This can be done using sun path diagram and the shadow angle protractor. From the Fig 31 length of the shadow (l) cast by the windowsil height (H) can be found out by eq. $l = H.\cot \alpha$.

Using the computed values of $\cos\theta$ and $\cot \alpha$ from appendix-9 in the equation $d = h.\cot \alpha$ and $W = w \cos\theta$, the width and depth (horizontal projected) of the penetrated beam of sun light in the indoor space is computed and presented in Fig.32 for ready reference.

6.3.2 Degree of exposure of facade (in terms of the surface area) to solar irradiation - vs - variations on spacings in the depth of staggering between two adjacent and parallel vertical stripe of the same facade and its angle of orientation:

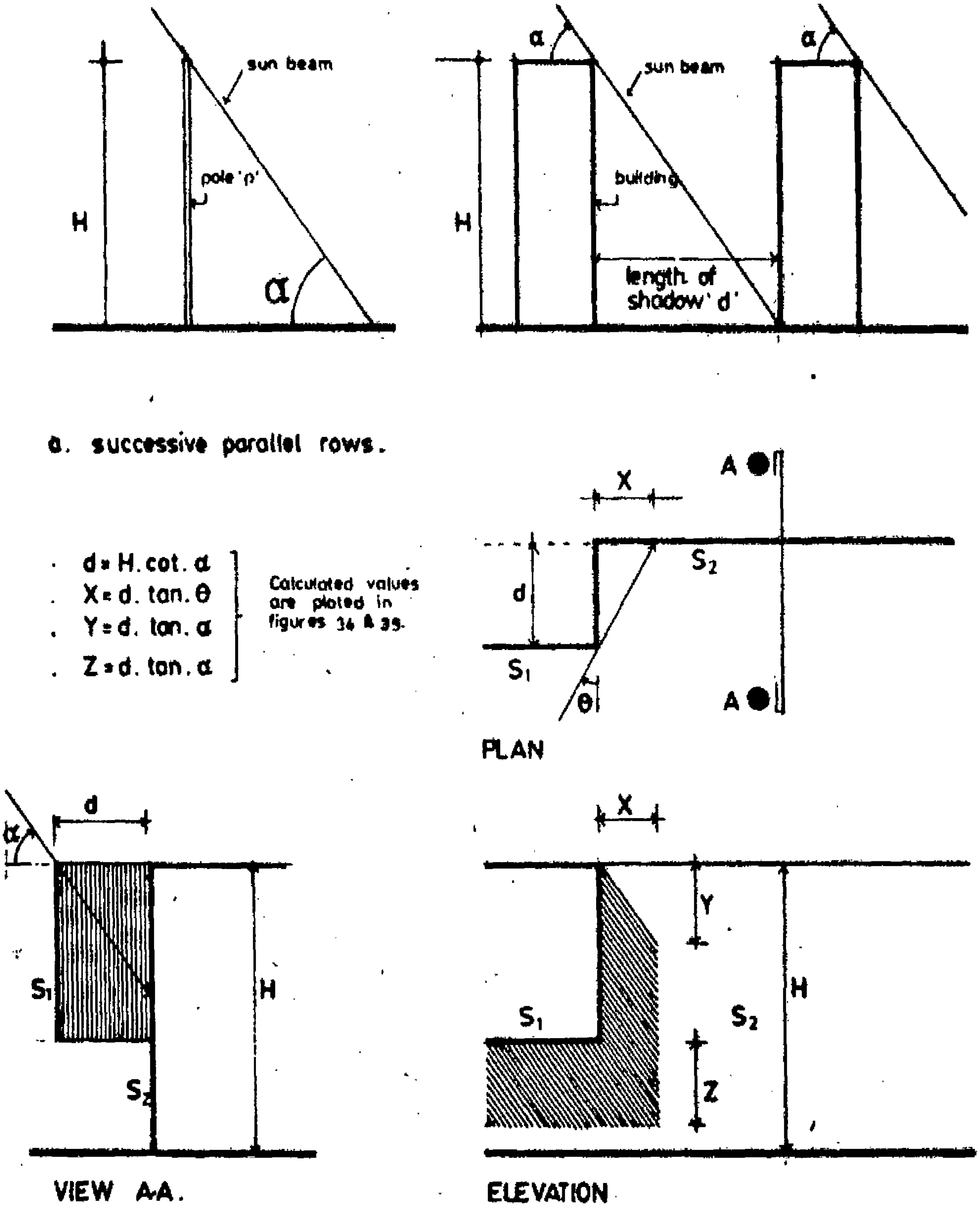
The relationship is investigated as follows from the Fig:33.

(a) For successive parallel rows: Let H, be the height of building and also the height of the vertical plate P' representing the height of the building. h-be the altitude of sun at a particular instant of the day. S_1 and S_2, be the two vertical strips of the facade under consideration. X-be the width of the shadow cast by S_1 on S_2. Y-be the distance of the end point of the sloping shadow line on S_2 from the top edge of S_2. θ and α be the horizontal and vertical shadow angles respectively from Fig:33. The length of the shadow is found by

$$d = H.\cot \alpha \qquad 40$$

The direction of the shadow can be determined from the azimuth(Z) of sun at particular instant of the day. With the partinent information the appendix-10 is developed and presented graphically in Fig:34.

(b) For depth of steggering: Again from the Fig:33



b. depth of staggering and / cantilever.

FIG: 33 Exposure of Facade to direct Solar radiation (appendix: 10 & 11.)

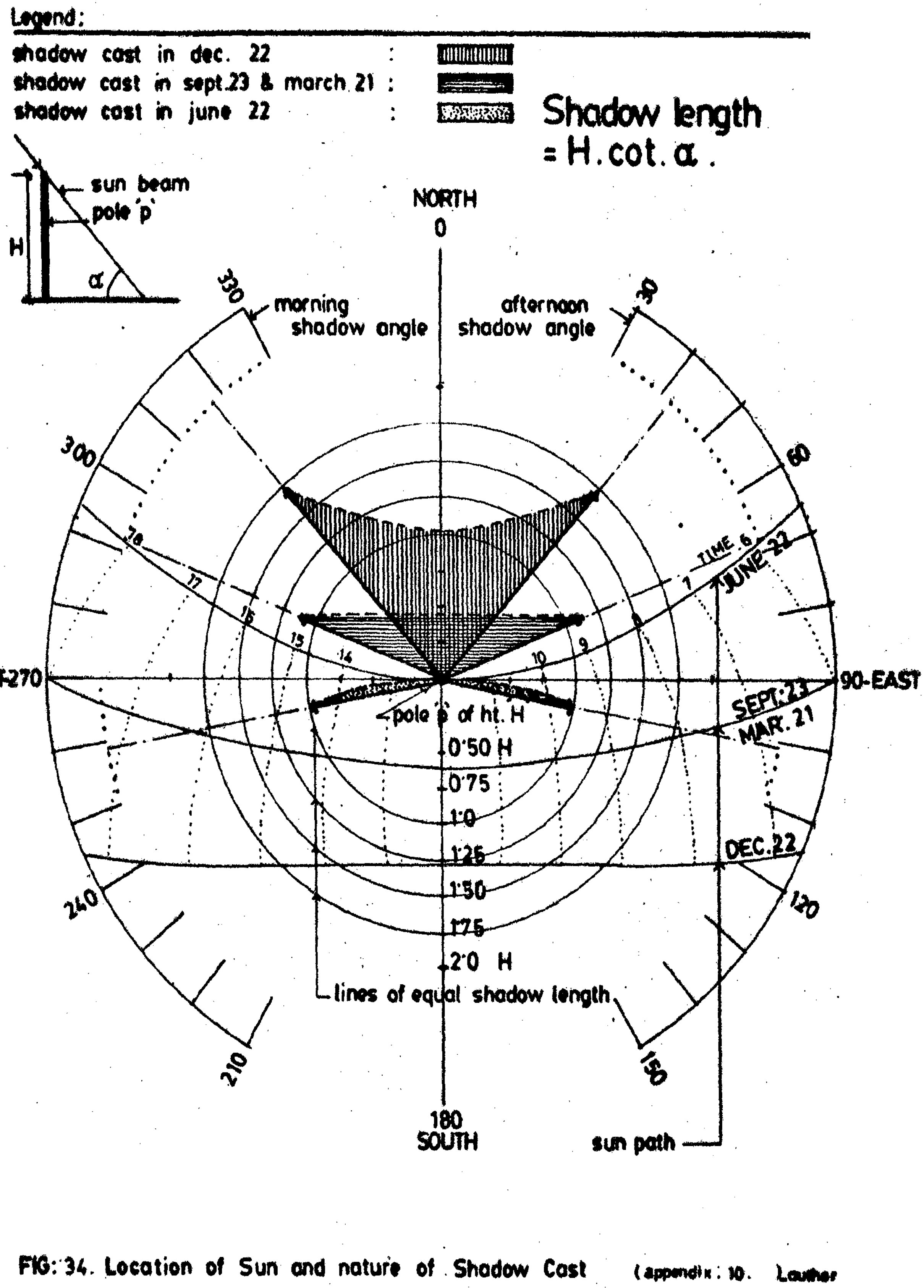


FIG: 34. Location of Sun and nature of Shadow Cast (appendix: 10. Lauther it can be seen that when d = 0, X will be equal to zero and there will be no shadow on the surface S_2. Also when d' increases, value of 'X' and 'Y' will increase reaching the maximum when 'Y' equals 'H'.

$$d = H \cot \alpha \qquad 40$$

This may be called the critical value of 'd' when 'd' increases further, value of 'X' and 'Y' remain unchanged. Therefore, for certain orientation of facade and for certain instants of the day, changes in the values of 'X' and 'Y' will occur for the values of d between d = 0 and d = H cot α. And it is in this range that the relationship between the area under shade on S_2 and the depth of Stagerring d, needs to be studied. The pertinent relationship can be expressed as follows

$$X = d \tan \theta \qquad 41$$

$$Y = d \tan \alpha \qquad 42$$

For the various instants such as the mid-morning, the mid-day and the mid-afternoon of particular days, θ and α will have definite values for a specific orientation and/degree of exposure of a facade to solar irradiation expressed in terms of the values of 'X' and 'Y' will depend only on the variations of 'd'. Values for θ and α for various orientations at the different instants of the required days is determined as before by using the sun path diagram and the shadow angle protractor and the computed data is tabulated in appendixll.1 for Dhaka.

Using data from the apeendix-ll.1 in the equations 40, 41 and 42, the values of critical 'd' 'X' and 'Y' can be computed for the various orientations and at the required instants of the days. These values are tabulated in appendix-ll.2. The degree of exposure of facade to solar irradiation at the required instant of the days for the different orientation can be readily read from the Fig:35. As the

Legend:

		june 22	sept 23 & mar 21	dec 22
mid-morning	:	o—o—o	▷—▷—▷	●—o—●
mid-day	:	o- -o- -o	▷- -▷- -▶	●- -●- -●
mid-afternoon	:	●- -●- -●	▶- -▶- -▶	●- -●- -●

$$d = H.\cot.\alpha$$

Note: refer to fig: for 'd'

– Maximum depth of staggering equal to height of building is good enough to shade the adjacent wall in summer and lit it in winter.

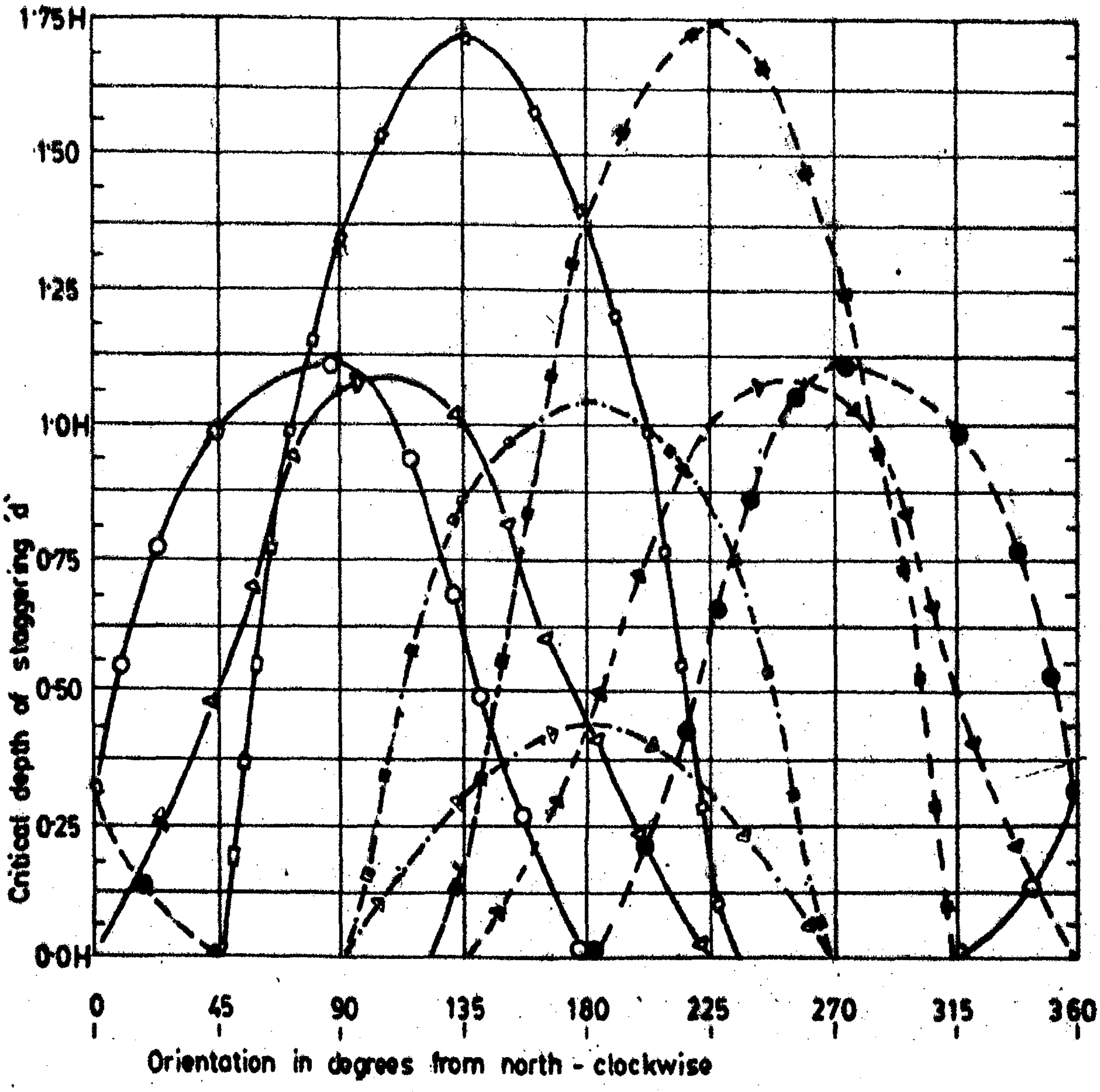


FIG: 35·1 Exposure of Facade to Solar Radiation (appendix: 10 & 11.). author

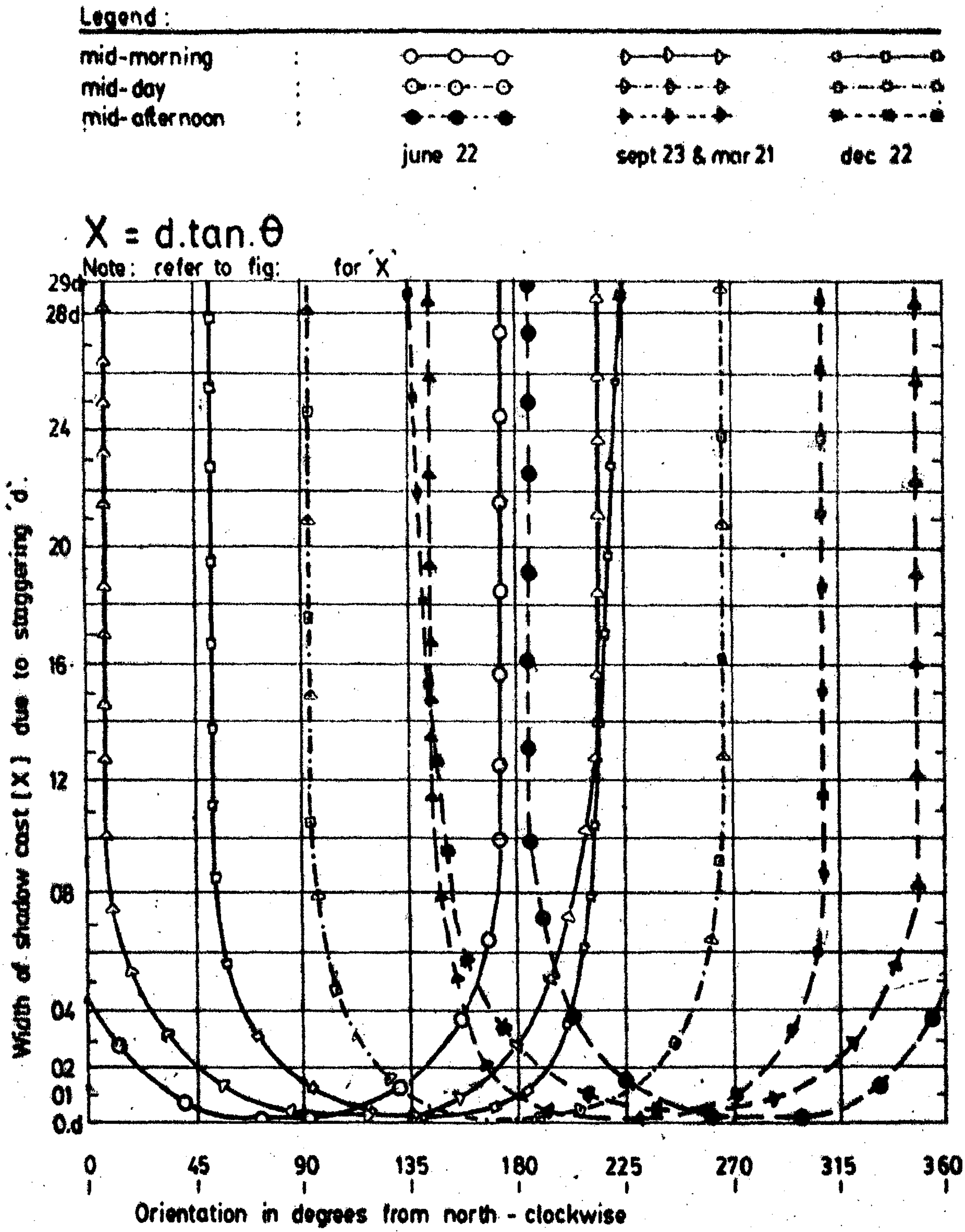


FIG:35·2 Exposure of Facade to Solar Radiation (appendix : 10 & 11. [illegible])_ author

Legend :

mid-morning	:	o—o—o	▷—▷—▷	✱—✱—✱
mid-day	:	o···o···o	▷·–·▷·–·▷	✱·–·✱·–·✱
mid-afternoon	:	●---●---●	▲--▲--▲	✱--✱--✱
		june 22	sept.23 & mar 21	dec 22

$Y = d.\tan.\alpha$

Note: refer to fig: for 'Y'

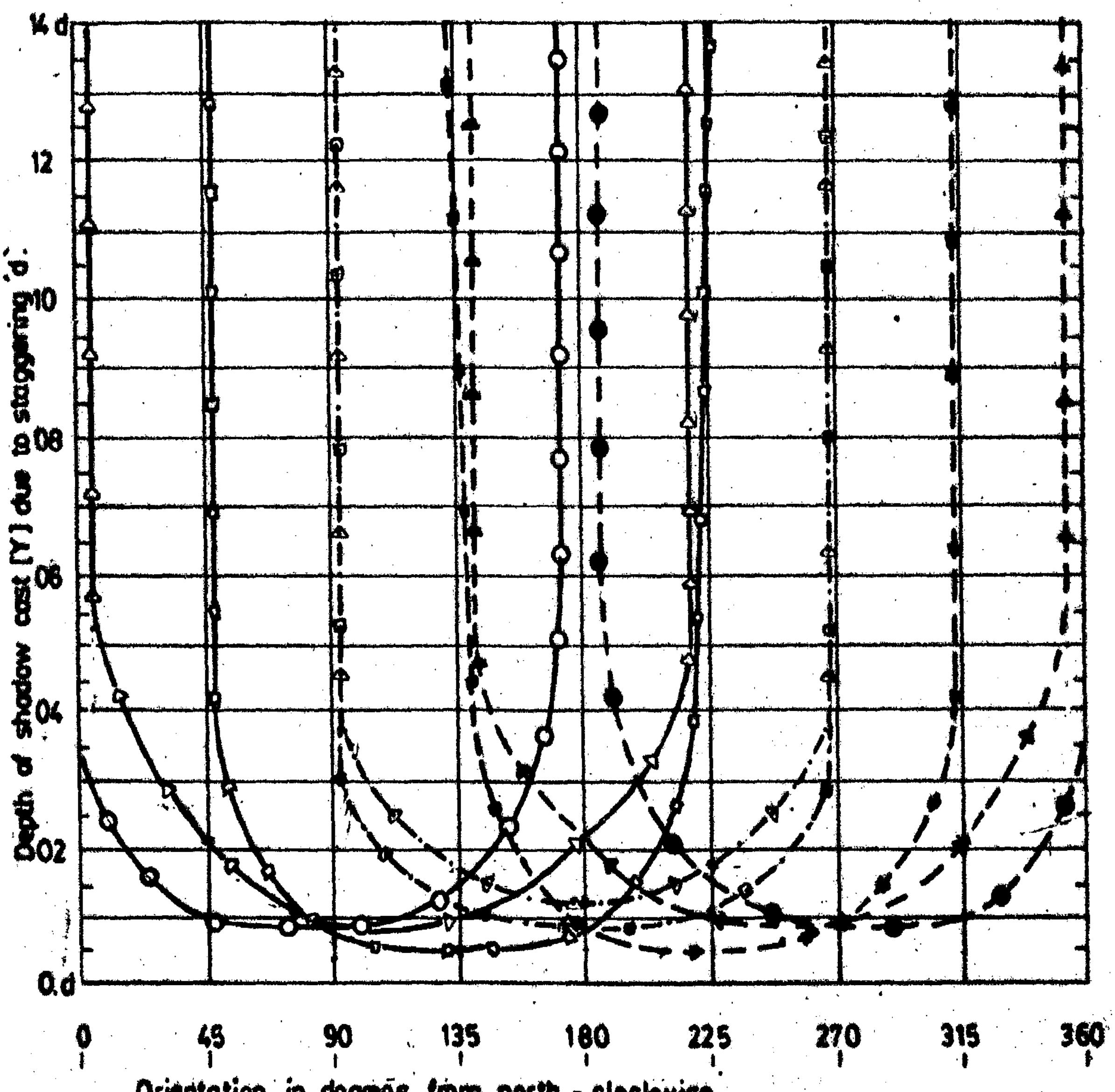


FIG:35·3 Exposure of Facade to Solar Radiation (appendix: 10 & 11.)..author a corollary, we can find the vertical coverage(z) by the shadow cast by the cantilever of depth 'd' by the equation $z = d.\tan\alpha$ (values are same as of 'Y') from the Fig.33.

6.4 Solar heat transfer into the building:

In thermal design work it is only necessary, during preliminary design stages, to compare the performance of construction assembly against an alternative choice for the same area. Designing of enclosing shell to keep its inside surface temperature near to the desired air temperature make it a design for comfort(38). It may be noted here that inside surface temperature of a construction can be found out by the following relationship:

$$t_s = t_i - [\ h_o \times U \times (t_i - t_o)] \qquad 43.$$

where t_s = inside surface temperature, ^oC
t_i and t_o = inside and outside air temperature, ^oC
h_o = surface or film resistance
U = usual symbol.

ASHRAE(5) is an authoritive source for all thermal properties of materials and for all methods and equations. For thermal design calculations by architects, the thermal conductivity of common materials shown in table:6 may be used. Although heat transfer through the envelope is not a critical factor for Dhaka yet the solar heat transfer into the building fabric may be studied as follows:

6.4.1 Extent of solar heat infilteration through the envelope (expressed as a fraction of the incident solar radiation on the surface)-vs - variation in the U-values of the envelope and the solar absorptivity (a) and surface conductance (h_o) of the outside.

This relationship is expressed in terms of the solar heat gain factor (Art. 4.3 and 4.4). The outside surface conductance is a function of the nature of the surface and the amount of air movement post the surface (Fig.36). The values are available in published sources, some of them for common building surfaces at different wind speeds is given in table :6(58).

Table: 6. h_o values in w/m^2K

Wind speed parallel to surface in m/s	Nature of surface				
	glass/ metal	Plaster/ timber	Concrete	Brick	Stucco
Still	8.5	8.5	8.5	8.5	8.5
2	12.8	13.5	14.6	15.2	16.8
5	26.5	32.8	42.4	47.6	61.0
10	46.5	55.7	74.5	83.5	107.0
15	63.9	76.6	102.2	115.0	147.0
20	81.3	97.6	130.5	146.6	187.5

Some of the K and U values of common materials are shown in table 7 and (appendix 12 for common U-value).

Table:7 K-values of building materials in w/m.k.(35).

Material	K-value	Material	K-value
Aluminium	198	Copper	380
Lead	34.6	Steel	48.3
Zink	112	Aerated Concrete (400 kg/m3)	0.086
Asbestos Cement	0.75		
Breeze block	0.17-0.35	Aerated Concrete (500 kg/m3)	0.103
Brick work	0.7	Aerated Concrete ($650\ kg/m^3$)	0.138
Concrete	0.7 -1.9	Aerated Concrete (800 kg/m3)	0.210
Plaster of Paris	1.09		
Rubber	0.2	Vermicole Concrete	0.08-0.2
Glass	0.5 -0.8		
Timber	0.2		

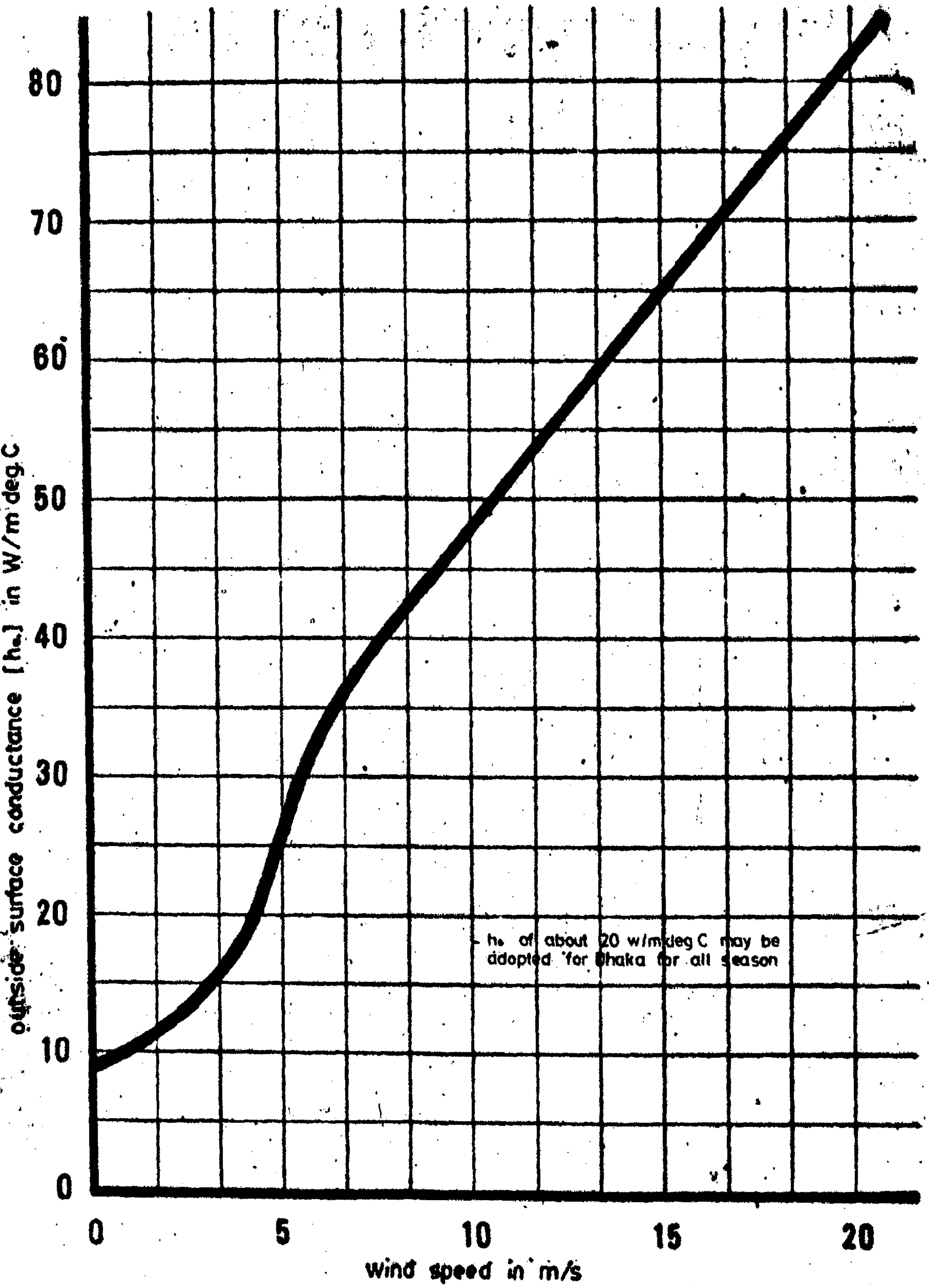


FIG: 36. Relationship between wind speed and h_o for smooth surface (33)

The following are the reflection levels of certain building materials(30) i.e. silver gray slates 1/5; red clay tiles 2/5; uncoloured red concrete tiles 1/3; white cement-fresh 1/2; after twelve month 3/10; new galvanized iron 1/3; white washed surface 3/4, very dirty object 1/10, polished copper 4/5; tarnished copper 1/3. Absorption coefficient of various colours is shown in table 8.

Table: 8. Absorption Coefficient of Various Colour(7)

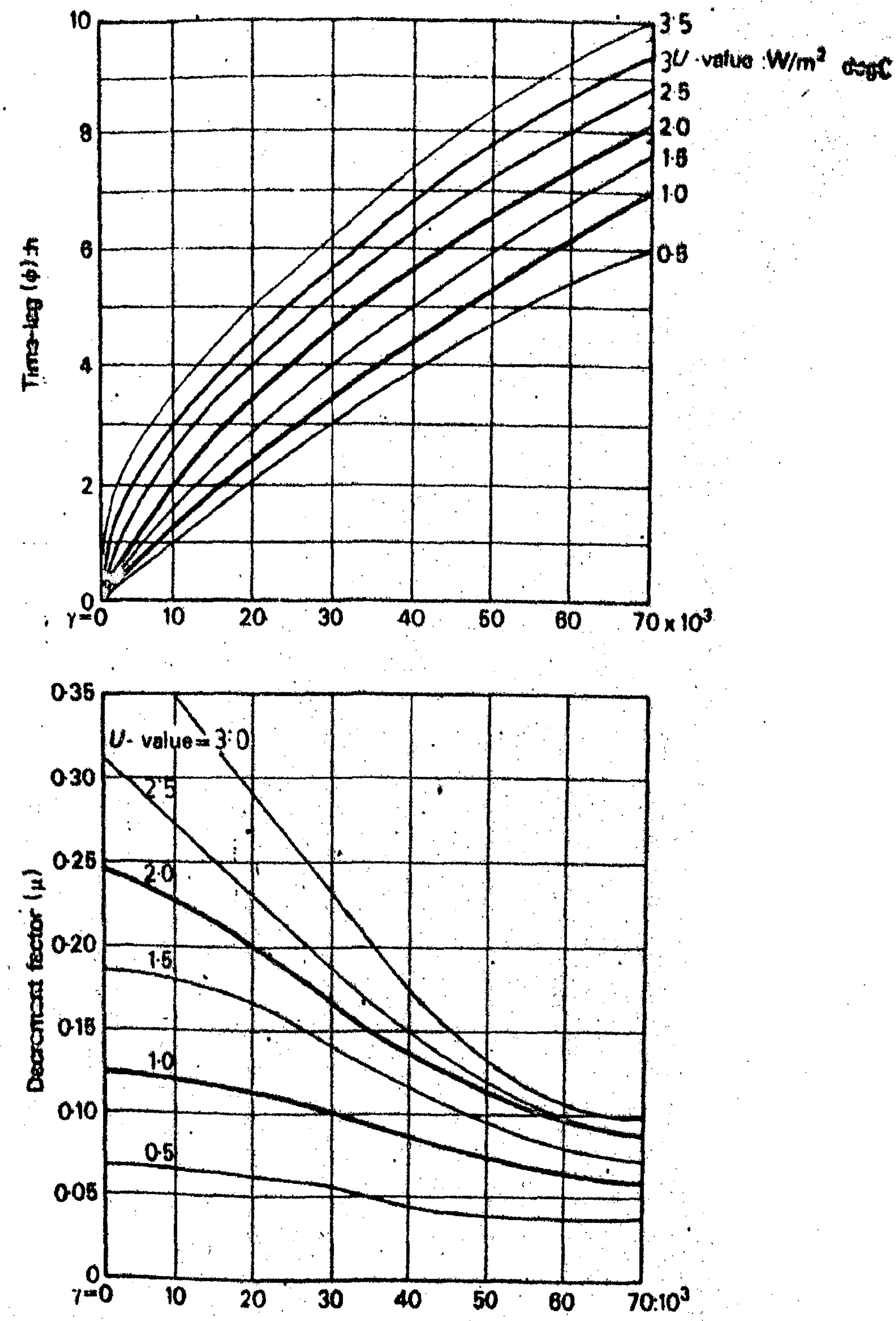
New white washed surface	10-15
White oil paint	20-30
White marble	40-50
Medium gray	60-70
Brick, Concrete	70-75
Glossy black	80-85
Matt block	90-95

White washed is clearly the best reflector, but since it needs constant renewal, white spar chipings are worth noting as a good alternative and a more permanent top surface in Dhaka.

Table:9 Temperature beneath flat roof covering on a Sunny day(23)

Description of roof covering	Maximum temp. °C
Felt - 2 cm asphalt-sand finish	43
2cm asphalt - aluminium paint	37
2cm asphalt - white spar chipping	26
2cm asphalt - white cement wash	26
2cm asphalt- white wash	23

In Dhaka climate, however, where air movement rate is typically low, it is reasonable to assume a constant value for $h_o = 20$ w/m^2 deg C (39) then equation 35 becomes



Conductance - capacity index: $\gamma = \left(\frac{d \times c \times b^2}{2k} = \frac{d \times c \times b}{2C}\right) = \frac{b^2}{2K}$

where d = density, kg/m³

c = specific heat, J/kg deg C C = conductance (W/m² deg C) = $\frac{k}{b}$

b = thickness, m

k = conductivity, W/m deg C K = diffusivity (m²/s) = $\frac{k}{d \times c}$

FIG: 38 Conductance - Capacity Index [29]. (appendix: 12.)

$$\frac{q}{I} = \frac{a \times U}{20} = 5\, a.U. \qquad 44$$

Thus the solar heat gain factor is a function of U and a, making it easy for general calculations from the table 8. The Table 10 shows wall U-values needed in Dhaka for a given wall surface temperature requirement. For ceilings the U-value may be reduced by 15%.

Table: 10

Wall Surface temperature	60	62	64	66	68	70	72	74	76	78	80
Suggested U-value	0.4	0.36	0.3	0.24	0.18	0.13	.08	.06	.05	.04	.03

In winter, surface temperature about 5 deg. below indoor air temperature will generally provide satisfactory radient comfort conditions(20).

6.4.2 Effect on the decrement factor (μ) and time-lag(ϕ) produced by the envelope-vs- variation in the thickness of the envelope, the nature of its construction and its density.

These can be found out experimently or can be found out from the published sources. The materials with long time-lag(Q) are generally dense and heavy weight and conversely, that is, light weight materials which enclose, trap, or contain a film of air, has shorter time-lag and hence lower U-value (appendix:12) A rule of thumb for massive masonry, west and east concrete walls is ϕ = 10 hours for each 0.3 m thickness(Fig:37). It may also be noted that high decrement factor will have a reduced maximum temperature in day time but an elevated minimum at night, taking ventilation to be constant throughout the day.

6.5 Summary of analysis

a. In summer, southern facade do not get any sun throughout the day but northern facade gets low altitude morning and evening sun.

b. In winter, southern facade gets the sun throughout the day, since sun altitude is low it penetrates deep into the building.

c. Northern facade receives minimum radiation, throughout the year.

d. East and west facade gets morning and afternoon sun respectively throughout the year amounting to almost $700 w/m^2$.

e. In March and September, maximum radiation of about $650\ w/m^2$ is received on orientations 135° to 225°, almost throughout the year.

f. In December, years maximum radiation is received on orientation 135° to 225° amounting to about $700\ w/m^2$.

g. Deepest and widest light penetrates in winter i.e. about 1.7 times the height and almost equal to width respectively of the opening in orientations 135° to 225°.

h. Largest shadow is cast by the building towards east and west 48°N in winter. Shortest shadow is in summer and sun is perpendicular on the building in June.22.

i. Maximum depth of staggering equal to height of the building is good enough to shade the adjecent wall in summer and lit it in winter.

j. Direct use of sun or use of thermal capacity of material are the two approaches, suitable for Dhaka's thermal design.

k. Low thermal capacity light weight materials giving short time-lag gives better performance.

l. Dhaka's climate suggest on exterior surface conductance of about $20\ w/m^2$ deg C.

7.0 FORM PERFORMANCE AT A GLANCE AND RECOMMENDATIONS:

It is a common knowledge that whereas the fabric of a building last for a hundred year, the system for thermal controls within buildings last for a shorter time and hence more emphasis should be put on envelope of the building for economical thermal design. The outcome of this study will help in designing better buildings for thermal comfort. The following are the inferences, recommendations and summarized points of the study.

7.1 The clarity of the air and radiation

Rain, fog or cloudiness, which is a common phenomenon in Bangladesh, markedly reduces the degree of solar radiation through the windows, and naturally at night the degree of solar radiation through the windows will approach that usually associated with windows facing north. Allowances must also be made for shading of the window. If part of the window is not subjected to direct sun light, the value for north facing window should be taken for this section, whatever the compass direction. This will very with time of the day and allowances for the length of the shadow must be made (Fig:30).

7.2 Orientation and Building

In winter, the maximum amount of heat gain is obtained through south facade (maximum by window) amounting to about 700 w/m^2. In the spring and autumn, the windows facing south east get the greatest heat gains in Morning, and the windows facing south-west get the greatest heat gain in the afternoon, both about 650 w/m^2. In summer, the rooms facing east tend to be the hottest in morning and those facing west, the hottest in the afternoon. Surprisingly enough, rooms facing due south do not get over-hot in summer. They register their heat gain in March and September(Fig:29).

7.3 Principal facade and radiations

Amount of solar radiation on east and west facade is nearly equal (Fig:30), but in eastern facade, it is less pronounced indoors due to the cool environment, unless ofcourse the eastern facade is all unshaded glass area. Reverse is the case in western facade, and hence, the western facade should be reduced or well protected or insulated by varendahs, creepers, plants or cavity wall with no openings at all. Glass area is a definite disadvantage, unless properly shaded. On western and south-western facade 'egg-crate' louvres (Fig:40) can be purposefully used, but it is expensive. Required dimensions of louvres, staggering etc can be directly calculated from Fig:31-35. The Fig:39 gives the same in nomogram form for ready reference.

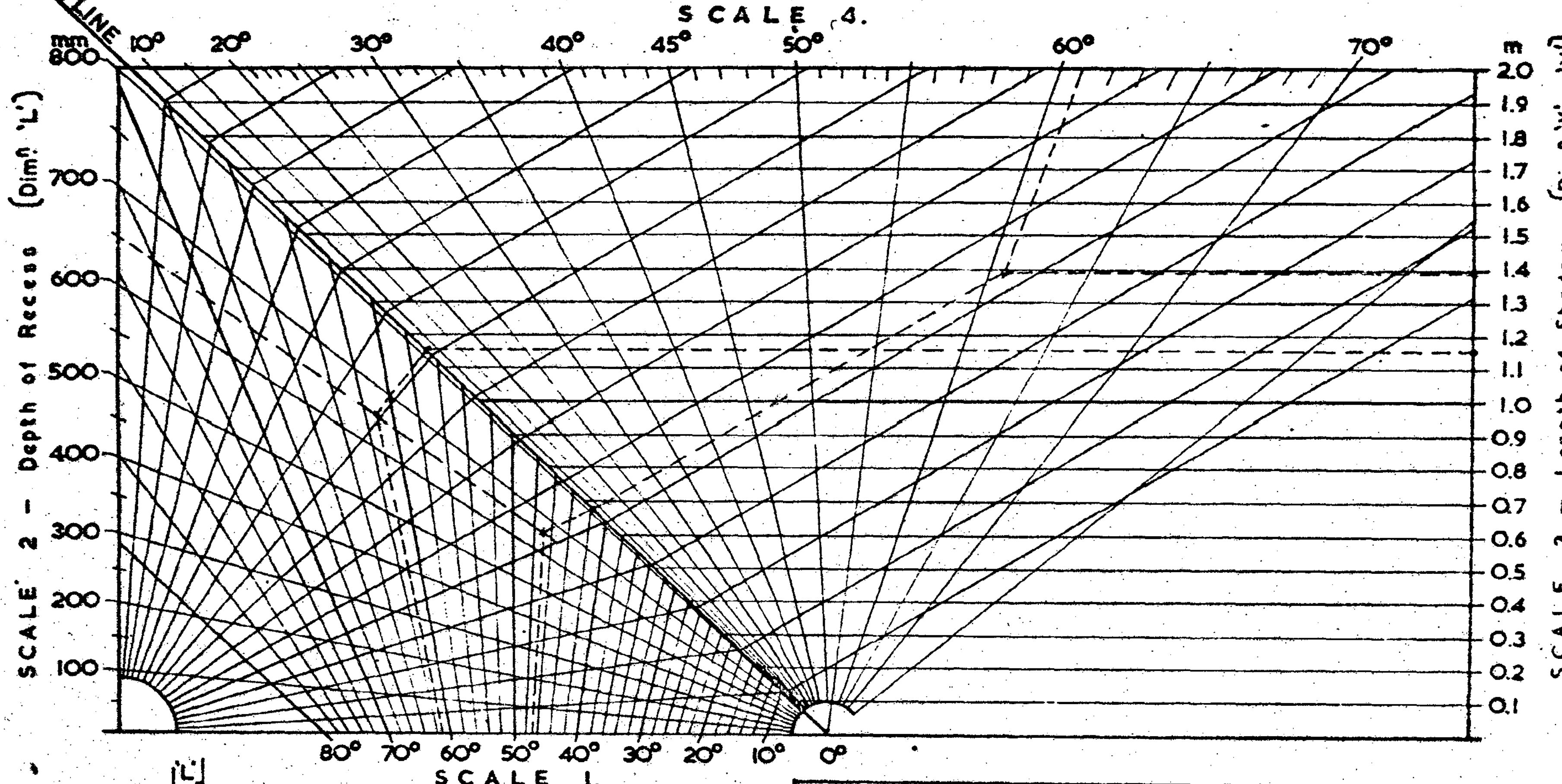
A south facade receives much larger solar radiation during winter than that during summer (Fig.30). Even a small projection(Fig:39) over the windows on the south facade can cut off direct summer sun and allow it during winter and perhaps the most advantageous aspect for south facades in Dhaka.

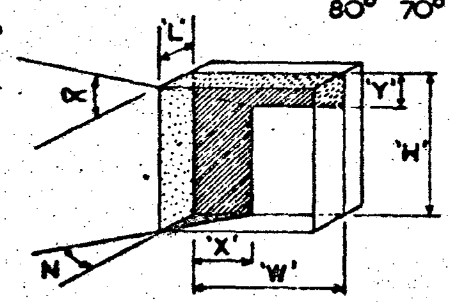
Except during early morning or late afternoon in summer the sun does not shine directly on the north facade and hence, much easier to effectively cut off the sun on this facade by vertical louvres on either side of the opening Fig:30).

7.4 Time of day and performance of building:

In almost all cases the bulk of the heat passing through the window goes through in a few hours of the day only. Again, the season makes a difference. The maximum radiation inwards takes place in winter around mid-day. But in spring and automn, it is around 9 a.m. in the morning

FIG:39. Sun Shade Nomogram [refer to fig: 30-35]





Sunlit Area – $(W-X)(H-Y)$

$X = L \tan N$

$Y = \dfrac{L \tan \alpha}{\cos N}$

L = Depth of Recess

N = Angle of Normality

∝ = Angle of Altitude

EXAMPLE: A window is recessed 650mm. The sun has an altitude of 61° and is at 47° from normal to the wall.

a) To find 'X' — Select 61° on Scale 1 and 650mm. on Scale 2. Proceed to their intersection and thence radially to the Base Line. Read horizontally on Scale 3 where 'X' = 1,173m.

(b) To find 'Y' — Select 47° on Scale 1 and 550mm. on Scale 2. Proceed to Base Line as above and thence diagonally to intersection with 61° radial from Scale 4. Read horizontally on Scale 3 where 'Y' = 1.387m.

and 3p.m. in the afternoon, while in summer, the maximum amount of radiation may take place as early as 7 a.m. in the morning and 6p.m. in the evening. Naturally the windows most effected will be those facing east in the morning and those facing west in evening (Fig:30). In case of opaque wall, this information will help in selecting material with appropriate time-lag.

7.5 Distribution of radiation over the day

Appendix 11 shows the amount of solar radiation for Dhaka. Although the values give the average only, it must be realised that in fact nearly all this heat flows in during about seven hours in in winter and perhaps 16 hours in summer, and that hourly fluctuations even during the day are enormus. In most cases the maximum degree of radiation through the window is between five and eight times as high as average flow rate given in appendix-11. In the case of the windows facing south-west the maximum degree of radiation inwards can be as much as 15 times as high as the daily average quoted, which means that nearly all the radiation is concentrated over a period of two or three hours only, usually at noon.

Radiation is proportional to the difference between the fourth power of the absolute temperature of the radiating surface (the sun) and the fourth power of the absolute temperature of the receiving surface (the window) i.e.

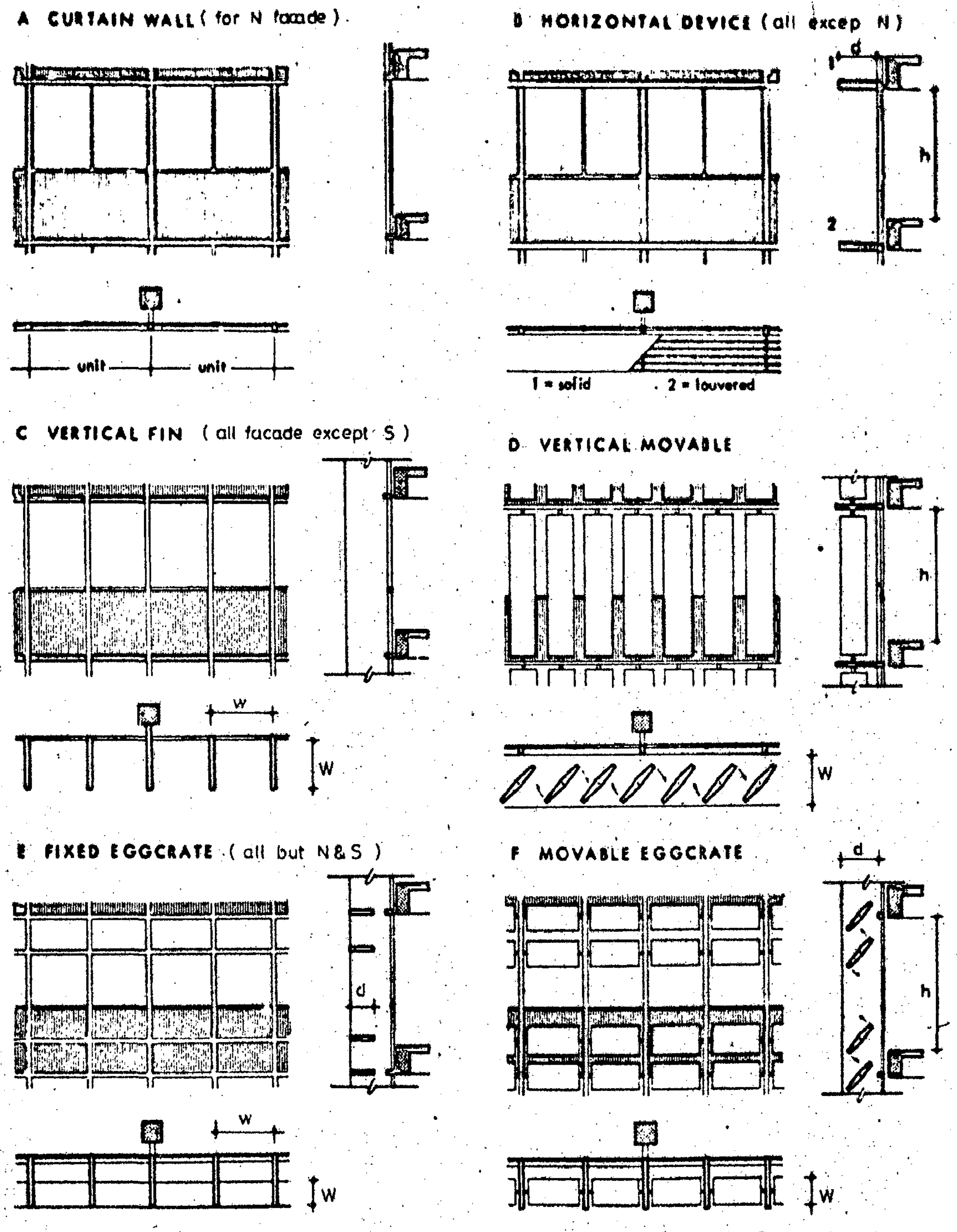
$$Q = e.s.(T^4_{sun} - T^4_{window}) \qquad 45$$

where Q = Heat received in w/m^2

e = emissivity factor of glass = about 0.6.

S = Stefan-Boltzmann factor = 5.68×10^{-8} w/m^2K^4

In the morning the window surface is cold and therefore the amount of radiation received is greater than afternoon, when the window has alreay warmed up. For this



Standard types of shading devices.
Note: d= h.Cotα & W = w.Cosθ (refer to fig 31 & 32)

FIG: 40 Standard shading devices that can be applied in Dhaka (42).

reason, windows facing east seems to get more heat radiation than windows that face west. This was also borne out experimentally in all the results obtained(18).

7.6 Compromise between various factors

Selective ventilation throughout the year results greater comfort, therefore, little compromise in orientation can be made (Fig:41) i.e. 0°-30° tilt from prevailing wind does not make marked difference. Suitable windows, located properly ensures better wind movement (appendix:2-4) In all cases, rectangular buildings, from radiation and wind point of view is best suited to Dhaka, ofcourse, the building should be planned, with arrangement of individual rooms depending on type and time of occupancy. A typical example of residence is given in table 12.

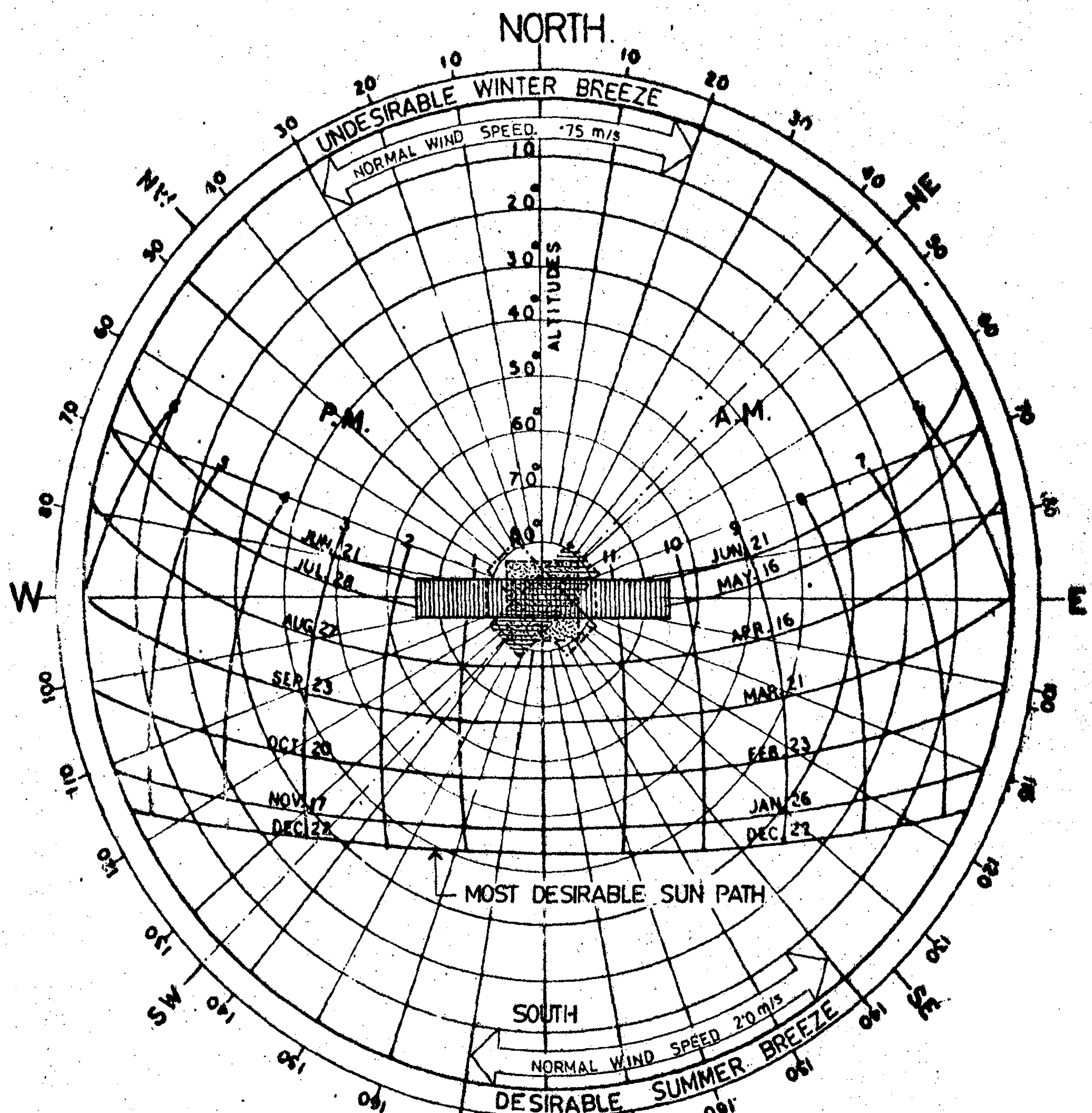
Table 12. Location of spaces in a residence for Dhaka

Room/Orientation	N	NE	E	SE	S	SW	W	NW
Bed Room	–	√	√	√	√	√	–	–
Living Room	–	–	√	√	√	√	√	√
Family Room	–	–	√	√	√	√	–	–
Kitchen	√	√	√	–	–	√	√	√
Verendah	–	√	√	√	√	√	–	–
Bathroom	√	√	–	–	–	√	√	√
Library	√	√	√	–	–	–	–	–
Workshop	√	√	–	–	–	√	√	√
Garage	√	√	–	–	–	√	√	√
Thermal rating	Fair		Good			Fair	Worst	

Knowing the TSI, a fenestration can be designed for required indoor wind speed ratio and lighting conditions by using nomogram on appendix:13.

7.7 The nature of windows and shading

The values in the appendix:14.1, apply to normal



Legend

condition	desired basic aspect ratio	
_ ideal	1:3 to 1:7	
_ tolarable limit	1:1·5	
_ hostile	1:1	

NOTE
best orientation is south facing both from sun & wind consideration

FIG: 41. Desirable Orientation and Plan form for Dhaka ._author.

single glazing. For different types of windows there value must be multiplied by the following factors(1)

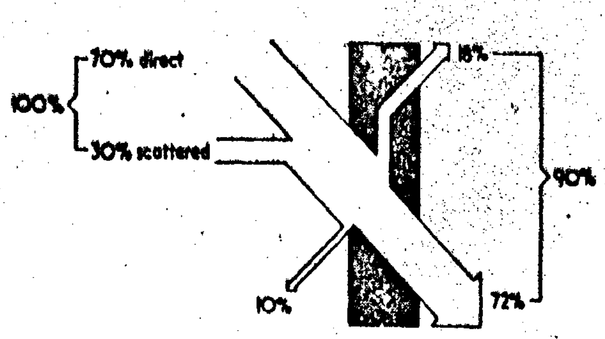
- Double glazing : 0.9
- Double glazing + Light plastic venetian blind:0.33
- Single glazing + Light plastic venetian blind, Light net curtain etc: 0.5
- Heat obsorbing glass : o.6
- Reflecting glass: 03

The results of the study by Givoni(25) shows the following performance of shading devices:

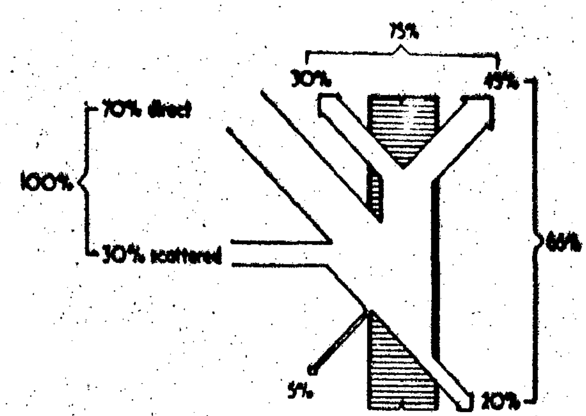
- External devices are much more effecient than internal devices.(Fig:40,42).
- The difference in effeciency between external and internal devices increases as the colour of the shade is darker.
- For external devices, the effeciency increases as the colour is darker, reverse is the case for internal devices.
- With effecient shading, such as external shutters, it is possible to eliminate more than 90 % of the heating effect of solar radiation(Fig:42).
- With effecient shading, such as dark coloured internal devices, about 75-80 % of the solar radiation impinging on the window may be expected to enter the building:

Table:13 Effeciency of some window shading(23)

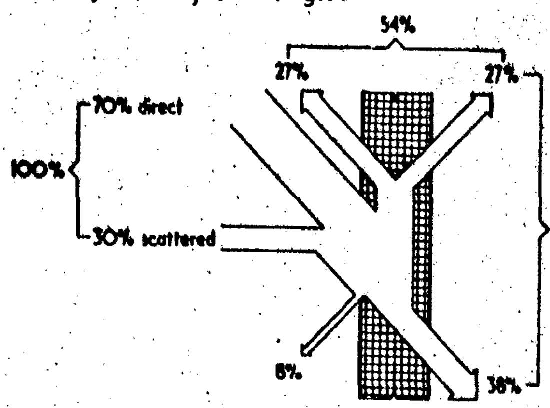
Type of shade	Colour	Fraction of gain through unshaded window
Internal venetian blind	Dark	0.86
Internal venetran blind	medium	0.74
Internal venetian blind	white	0.62
External venetian blind	cream	0.3
Conwan owing	Dark	0.25-0.35
External shading screen	Dark	0.22



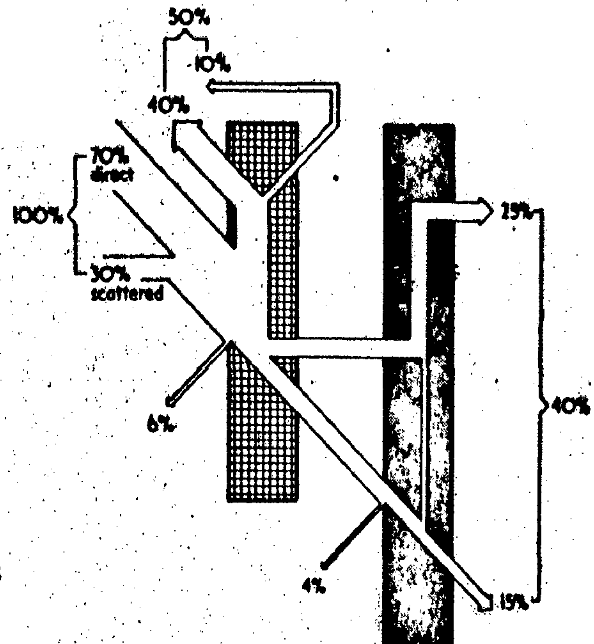
a) ordinary sheet glass



c) glare reducing glass



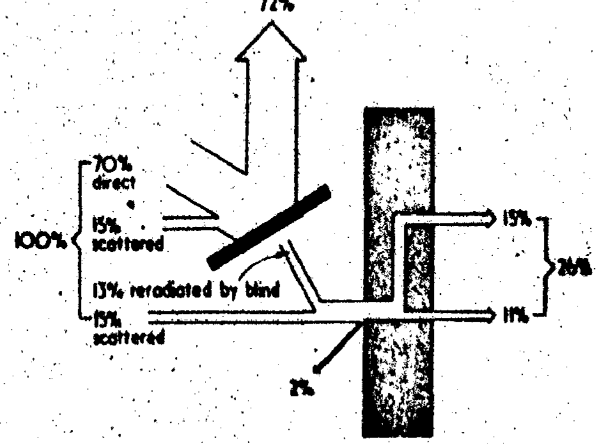
b) heat absorbing glass



d) panel of heat absorbing glass, freely suspended in front of glass

NOTE :

- Disadvantages of heat absorbing glass
  - i) absorption of heat causes thermal stresses within the glass, requiring special glazing techniques.
  - ii) much of the energy absorbed by the glass passes into the building : it behaves like a panel radiator, unless it is ventilated, or used with double glazing.
- Sheet glass [plain or frosted] under shade, is perhaps best suited for Dhaka condition.
- Polyester film fixed on plain glass is the latest concept in sun control applications.
- Venetian blinds as in "e" shades the glass, and reflects much of the incomming solar radiation.



e) same as "d" with alummium blind.

FIG:42. Effeciency of Different Means of Controlling Solar Radiation-[40].

7.8 Effect of shading device on glass windows:

The summer season for Dhaka is a period between mid-March to mid-July. This roughly is the time when complete shade is recommended. It is recorded, that during this period the internal temperature of an unshaded building on a sunny day exceeds the comfort level of about 30°C for Dhaka. Heat gain through a sun-lit glass area is many times higher than through an equal area of ordinary wall, and its affect is felt almost immediately, without any appreciable time-lag(53).

Table:14 Heat gain through various types of glasses, of radiation at normal incidence(25)

Type of glass	Direct Transmission	Due to absorbed radiation	Total
Clear glass	74	9	83
Window glass	85	3	88
Light heat absorbing glass	20	25	45
Grey glass	30	30	60
Lacquered	38	17	55

Note: A more recent technique is the developement of glass that reflects, rather than absorbs, radiation by being coated with a thin transperent layer of evaporated metal.

Shading devices applied in combination with glass modifies the thermal effect of glass (as stated in previous artical) and hence can be applied either externally, internally or between double glazing. They may be fixed, adjustable or retractable and of a variety of architectural shapes and geometrical configurations (Fig:40,42).

7.9 Building form and Thermal property of its envelope

The building form should be optimised to 1:3 (width to length) to reduce the impact of solar heat gain while at the same time admitting the maximum amount of natural day light, a contradiction in terms. The ideal proportion is 1.7, whereas tolarable one is 1:1.5, volume does not have significant impect in Dhaka context.

A fabric with a U-value range of 2.5-3.5 w/m^2deg C may be recommended for Dhaka. Required time-lag will depend upon the activity pattern in the building but in general, low thermal capacity material i.e. with minimum time-lag of about 1 to 2 hours is recommended for Dhaka. If for functional reasons some higher time-lag is needed than western/eastern wall may have a time-lag of 8-10 hours. Light colour roof top, east and west facade will improve the thermal performance.

7.10 <u>Proposal for further study in the line</u>

Architects as responsible professionals should be pacesetter in pushing for acceptance of climate effecient buildings and hence must place higher priority on climatically related design, in the stages of site selection, orientation, schematic design, design developement, detailing material selection and protective devices.

(a) Research has been done on optimization of building size, shape, bay size, etc for structural, spatial, lighting and economic considerations. This dissertation gives emphasis on the effect of sun on buildings, assuming other conditions of any warm humid area to be holding good for Dhaka. Therefore, future research would be needed to combine climatic consideration in the total optimization of building design.

(b) Detail review of existing buildings at Dhaka may be carried out to analyse the thermal performance of the buildings on account of its weatherizing elements and or design.

(c) Performance standards for weatherization of buildings should be established in local building bye laws to ensure the implementation of climate effecient buildings for more comfort with reduced active aids in future buildings.

(d) The analytical study carried out in this dissertation may be taken up with experimental models to show the validity of the mathematical and graphical findings. Central building research institute, Roorkee has got the required facilities.

(e) Well ventilated and damp proof basement structures have good potentiality as comfortable shelter in Dhaka, or atleast underground coolth can be effectively utilized in contemporary buildings with passive means. This field requires thorough research.

ADDENDUM: APPLICATION WITH SPECIFIC EXAMPLE

1. The Design Problem:

Here, a small practical problem associated with many constrains is takenup to demonstrate, in general, how an Architect can make use of the findings. However, it is not possible in this example to show the application of all the graphs developed, moreover ultimate coordinated decision must rest with the designer, but it can be safely claimed that the approach will make the decisions easier and more scientific.

The problem taken up is the "Sub-Divisional Engineer's (SDE's) Office" at planning commission campus, Sher-e-Banglanagar, Dhaka. General office timing is between 10 a.m. to 5 p.m.

A. Space requirement for SDE'S Office

Space	Approximate area(sq.ft.)
a. SDE'S Room	160
Attached toilet	40
Tea preparation space	30
b. Sub. Assistant Engrs.(2) Room	160
c. Office:	
Main room	360
Record + record keeper's room	180
Common toilet	50
Sanitary Store	160
Cement store	160
d. Appropriate size varanda and circulation spaces	
e. Outdoor stackyard in one patch	800

Note: Total building area not to exceed 2200 sq. ft.

B. Constrains:

a. Set back requirement: 18' from east and west and 6' from north and south property lines

b. Building shape: Regular square or rectangular plan without offsets.

c. Height requirement: Not to exceed 13.0'

d. Must follow general architectural style of the campus designed by Prof. Luis I. Kahn.

2. The Analysis for Design:

Solar radiation must be controlled from March to September. No comfort ventilation is required in November to February and hence cold winds should be especially restricted during these months. The favourable prevailing breeze is to be directed indoors by openings on positive and negative pressure zones, amounting to not less than 30 percent of the facade. Wind incident to wall at upto 45° can provide satisfactory ventilation and a target to reduce the incident solar radiation by about 20 percent on the surface by suitable design will be good enough. The following is the site condition to assess the extent of its flexity to achieve the desired target.

A. Basic Data:

Site Conditions of Proposed SDE's Office

a. Diurnal air temperature and relative humidity in the site:

	Temp. °C		R.H. %	
	Minimum	Maximum	Minimum	Maximum
Nov.-Feb.	13	26	60	70
March-April	21	32	70	80
May -Aug.	25	33	80	95
Sept.-Oct.	24	31	70	85

b. Wind speed and direction (Fig:43)

	Speed m/s	Direction
Nov.-Feb.	3.0	340° - 10°
Mar.-April	7.5	150° -170°
May -Aug.	8.2	140° -190°
Sept-Oct.	5.0	180° -200°

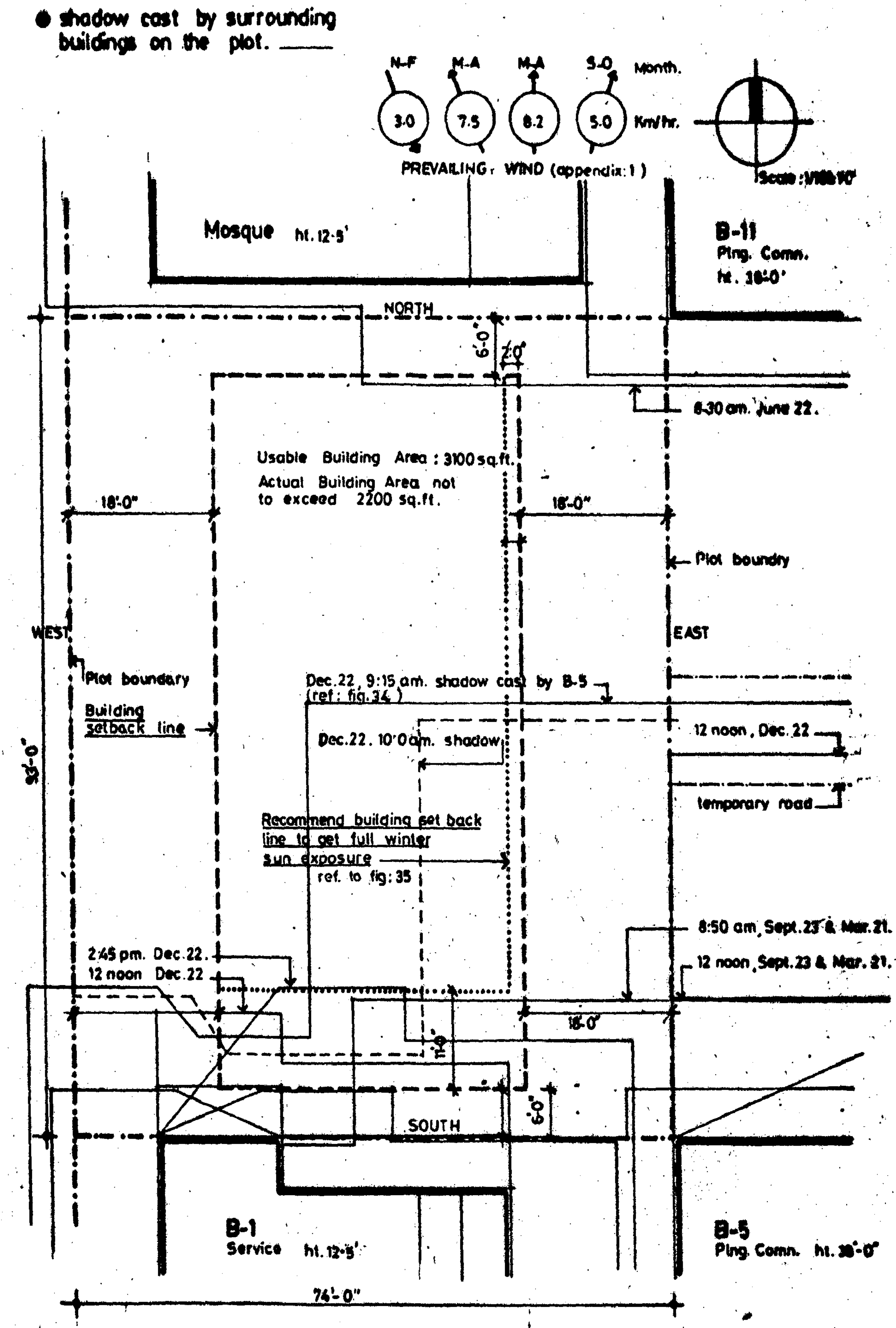


FIG: 43 Thermal Plot Plan for SDE's Office, Planning Commission Campus, Dhaka.

c. Approximate horizontal and south-vertical radiation(Fig:44)

	Horizontal:w/m^2	Vertical: w/m^2
Nov. - Feb.	320	570
Mar. - April	550	350
May. - Aug.	700	65
Sept - Oct.	500	355

d. Building lot shading problem(Fig:43): On the south-east of the plot there is an approximately 38'- 0" high building and on the south a building of about 12'-6" height exists. They cast long shadow on the plot during winter. Plot is a flat land.

B. Interpretation:

a. <u>The Plot</u>: The thermal consideration can be visualized better if placed on a plan of the building plot(Fig:43). The building lot faces east. It is a lot for service buildings in the peripherial land of planning commission campus. The lot has an area of 6882 sq.ft.(93'x 74').The zoning convention in the campus calls for a front and rear set backs of atleast 18' each and side set backs of 6' each. Thus, usable building plot is 81' by 38' along north-south axis.

The prevailing wind during the month of March to September is from south to south-east but in November to February it is from north to north-west. There is a possible shade problem from the adjoining lot extending 20' and 17' in from the east and south lot lines respectively, which leaves 2' and 11' respectively of the possible building area shaded on the east and south side(Fig:43). A further setback of 1' on the south is recommended to facilitate better light and ventilation indoors(Fig:44). Solar radiation per square meter of various vertical surfaces at different instants of the day for each season is ploted(Fig:44) to determine the desired layout and design elements for the proposed building.

M.M.= mid-morning at 8:30 am & 9:15 am. for summer & winter respectively.
M.A.= mid-after noon at 2:30 pm & 2:45 pm. for summer & winter respectively.
M.D.= mid-day at 12 noon.

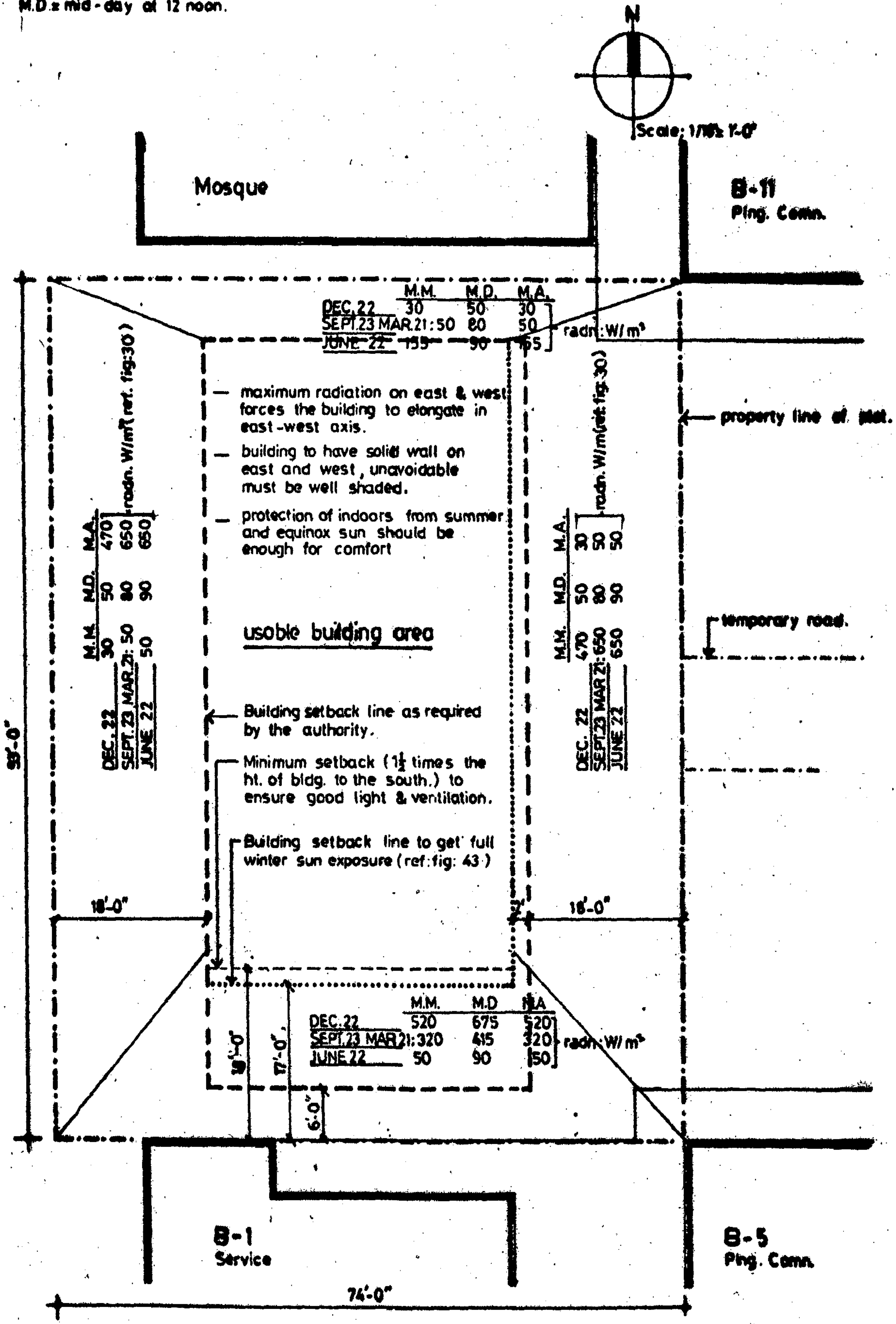


FIG: 44. Radiation plan for SDE's office at Planning Commission Campus, Dhaka

b. The Building: The strategy would be to provide maximum shade to unavoidable heat absorbing surfaces and also ample ventilation to remove the access heat. Reflective quality of exposed surface of unshaded wall contributes to inner surface temperature.

The heat gain beneath the exposed roof may be reduced by providing ventilation at ceiling level. White painted roof surface reflects about 80-90 percent of radiation and thus provides significant advantage in reducing internal heat gains. Since white wash need constant renewal, white spar chipings are worth noting, with about 50 percent reflectively, as a good alternative and more permanent top surface in Dhaka. It gives a maximum temperature of about 26°C beneath 10 cm R.C.C. flat roof covered with 2 cm. asphalt in a sunny day.

Unplastered ceramic brick at the exterior has got a very smooth surface in itself and may be made about 20 percent more reflective by painting it with transperent wax paint, which will serve the duel purpose of resisting water and radiation. A time lag of 2 to 4 hours is just enough to hold the transmission of solar radiation indoors upto late evening when the office is vacated. This can be achieved by providing 25cm thick solid brick walls especially in the exposed east and west orientations.

Shading devices should be such that while obstracting the sun, they do not reduce the baneficial effect of the breeze. A wall surface with small projections or depressions radiate less heat inside than a plain surface due to cooling effect by mutual shading and greater surface area being available for surface convection.

Window height above normal occupancy zone i.e.2.1 m above floor, does not contribute much to body comfort. Normal working plain is at a height of about 0.8 m, therefore it can be taken as window sill height to ensure maximum advantage of ventilation at body level. Windows are a source of heat gain and hence needs protection against the direct solar radiation in summer and may be allowed indoors during the cool hours of the day in winter.

c. Calculation of Louvres:

As discussed in Chap:5, horizontal projections on south facade and vertical projections on north facade is needed as external shading. However, horizontal projection on top of vertical members on north facade are required for protection of window against rains. The louvre/overhang size, for various orientations to exclude sun from indoors in the month of March to September and than gradually allowing it indoors to the maximum in cool hours of winter days, are calculated below:

As discussed earlier, the height of window openings will be about 1.3 m with its sill height at about 0.8 m. If a ventilator is to be provided, over each window upto the ceiling, to facilitate cross ventilation beneath the warm roof, than the horizontal projection will need to shade a height of 2.2 m i.e. (3 - .8). Taking a module of .75 m for window width (Ap:13.1), the depth 'd' and 'W' of horizontal and vertical louvres from eq. 38, 39 and Fig:31, 32, the sizes are as follows:

a. <u>South facade</u>:

d = 2.2 x .42 = .92 m (approx: 3'- 0'')

W = .75 x .34 = .26 m (approx: 10'')

In december 22, depth of the sun light received on the floor indoors starting from 3.5' from the wall[Fig:45(a)] is:

d = 2.2 x 1.38 - .8 x 1.38 = 1.94 m (approx: 6.5')

Therefore, vertical and horizontal louvres of approximately 3'- 0"depth will shade the specified window with ventilator in summer and will allow sun beam indoors in winter.

b. <u>East and West Facade</u>:

Depth of overhang required to shade the openings at around 9.45 a.m. and 2 p.m. is from the eq. 38, 39 and Fig:31,

Legend:

		mid-morning	mid-day	mid-afternoon.
– DEC. 22	———	9.15 am	12.0 noon	2.45 pm.
– SEPT. 23 & MAR 21	– – – –	8.55am.	12.0 noon	2.35 pm.
– JUNE 22	–.–.–.	8.30am.	12.0 noon	2.30 pm.

N.B. refer to figs: 31, 32, 34, 37

Design objective: exclussion of sun in march to september from indoors during office time of 7.30am - 2.0pm.

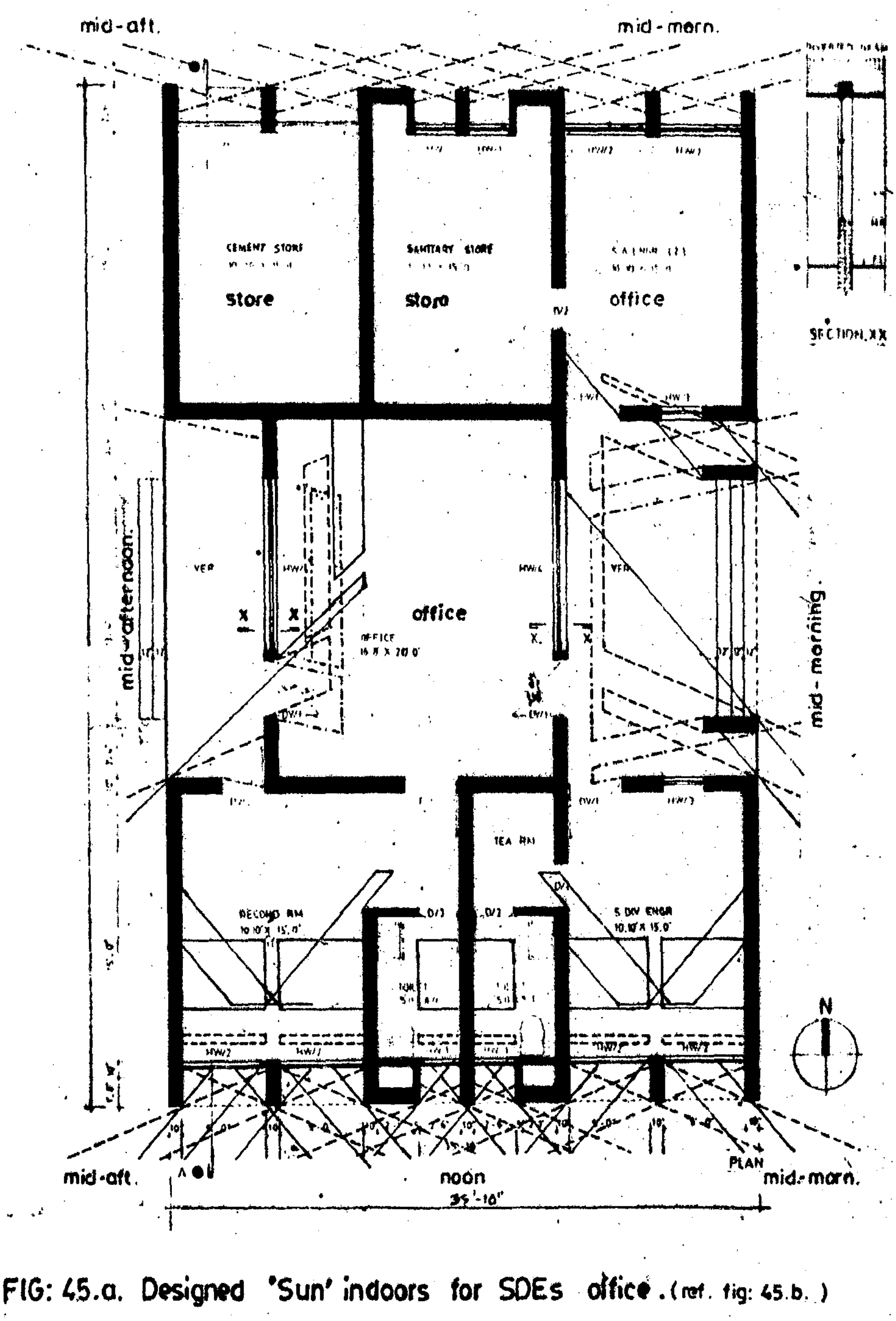
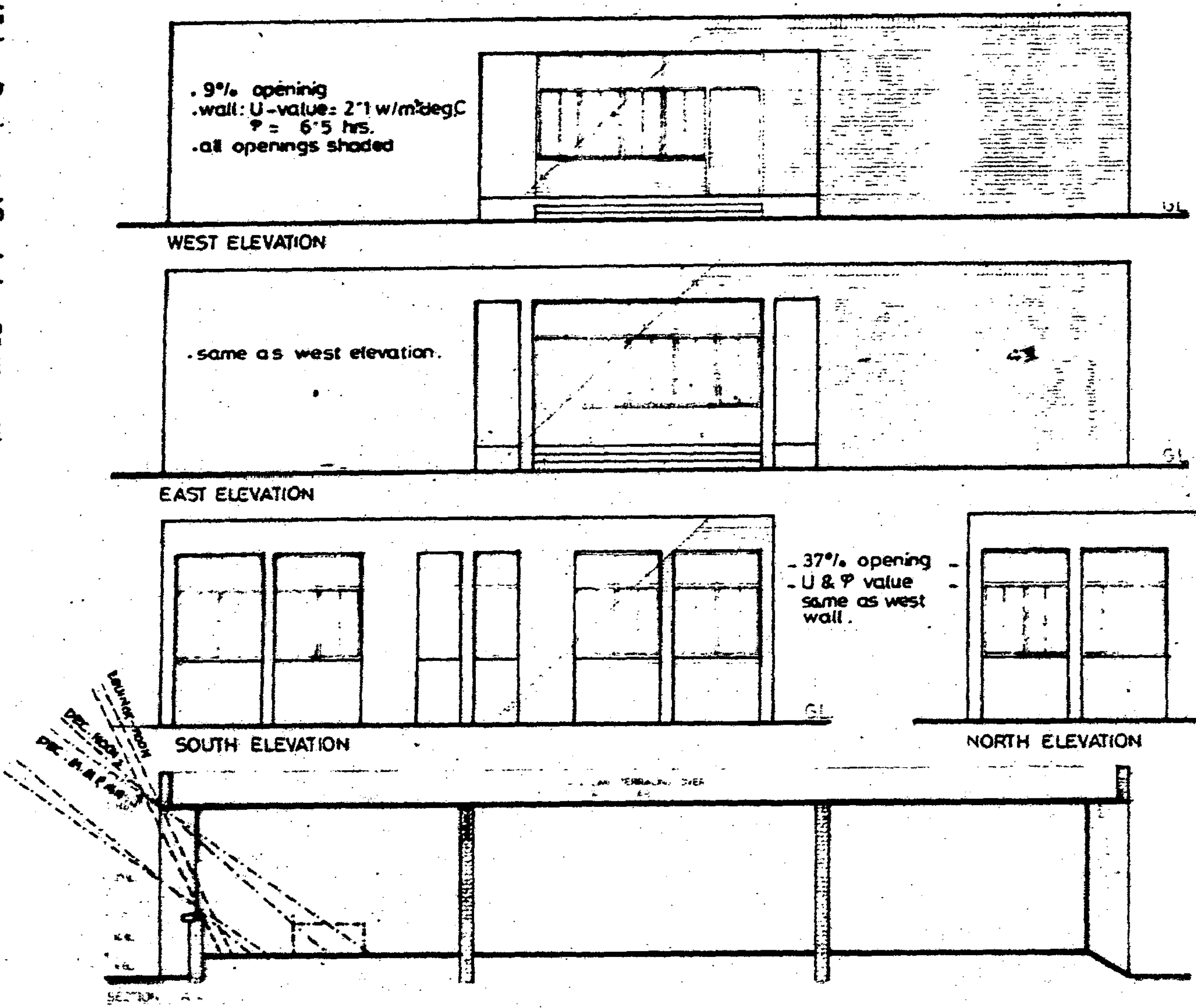


FIG: 45.a. Designed 'Sun' indoors for SDEs office. (ref. fig: 45.b.)



Reduction of solar radiation during its peak on clear day, by shading:

East & West facade:
june: peak radiation = 45 k.watts, reduction by shading 10·5 k.watt i.e. 23%.
sept. & march: same as june.
dec.: peak radiation = 32·4 k.watts, reduction by shading = 7·6 k.watt i.e. 23%.

South facade:
june: no usefull reduction possible.
sept. & march: mid-morning & afternoon peak radition of 30 k.watt. is reduced by 8·6 k.watt. i.e. 28%: mid-day 27%.
dec.: full radiation throughout the day is wellcomed on facade.

North facade:
june: mid-morning & afternoon peak radiation of 6·67 k.watt. is reduced by 2 k.watt i.e. about 30%. In other months, no usefull reduction is possible.

NOTE: about 20% reduction is good enough for Dhaka.

Other designed factors to contribute in better thermal performance:

- sun is excluded from indoors upto equinox but allowed in winter.
- components are treated to reduce heat gain from radiation.
- generous shaded openings at ceiling and body level for removal of warm-humid air by cross ventilation.

Note: performance is cross checked with window design nomogram in appendix: 13.

FIG: 45.b. Designed 'Sun' for SDE's office (ref: text & figs 43, 44, 45.a. and appendix: 13)

32 as follows:

d = 3 x .85 = 2.55 m(approx: 8.5')

Therefore varandah, if provided, on the east and west should be atleast about 8' deep [Fig:45(a)]. Espacial core should be taken of the eastern facade to prevent warming up of indoor during office time.

3. <u>The Design</u>:

Assuming the design criteria set in chap:4 as ideal condition and making use of the further studies in chap.5 and 6, the proposed building is designed [Fig:45,46]. Accepting the challenge of physical constrains, considering the environmental factors and respecting the users desire for comfort, the building is designed and its performance is checked with the help of multigraph in appendix:13, and is found to give satisfactory TSI conditions indoor.

The projects with better physical conditions will, naturally, yield to even better solution.

Note:

- Open space to built-up area ratio : 3·4:1
- Aspect ratio (along N-S axis) : 1:1·58
- Surface area to floor area ratio : 4·6:1.

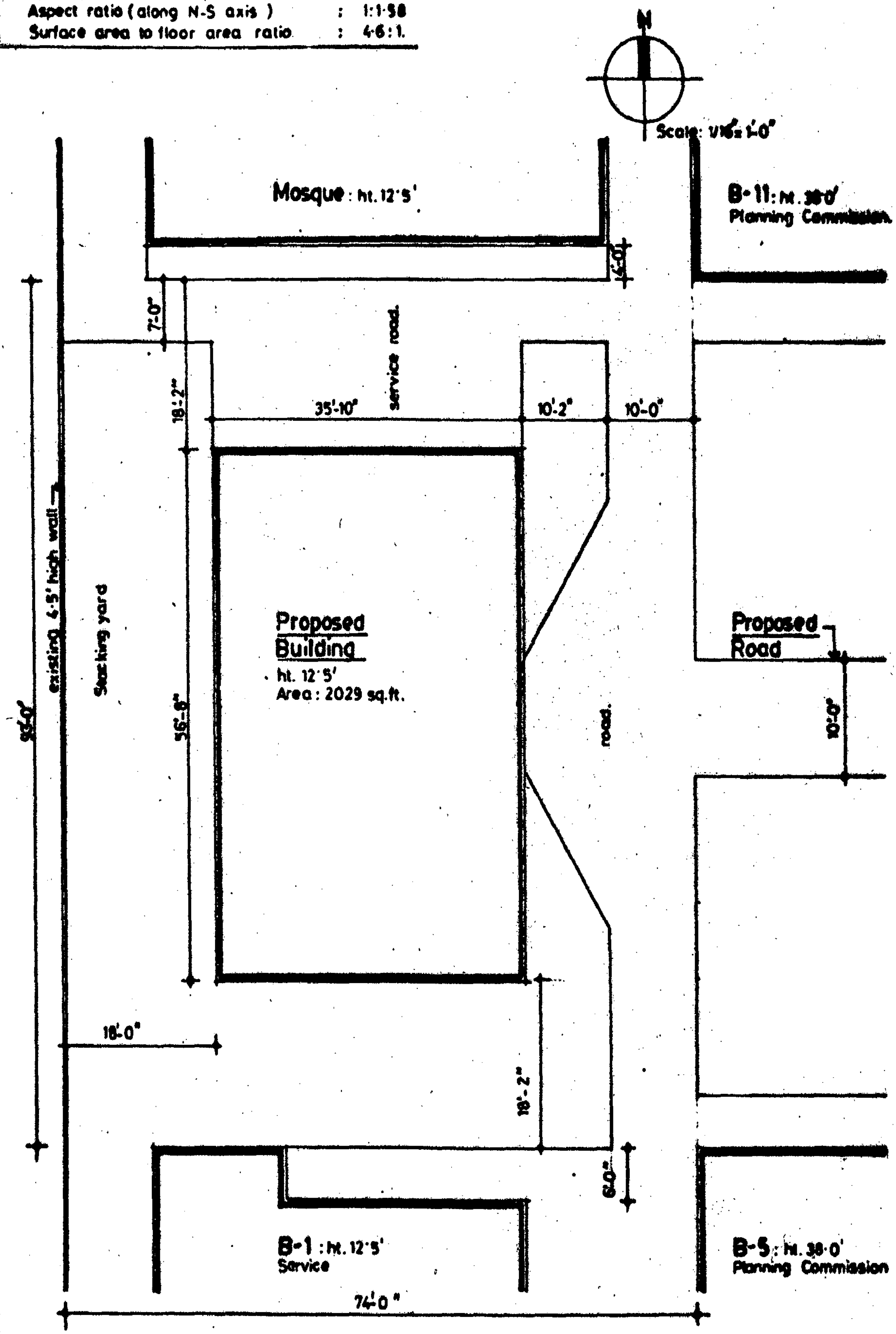


FIG: 46. Layout Plan of Proposed SDE's Office at Planning Commission Campus, Dhaka.

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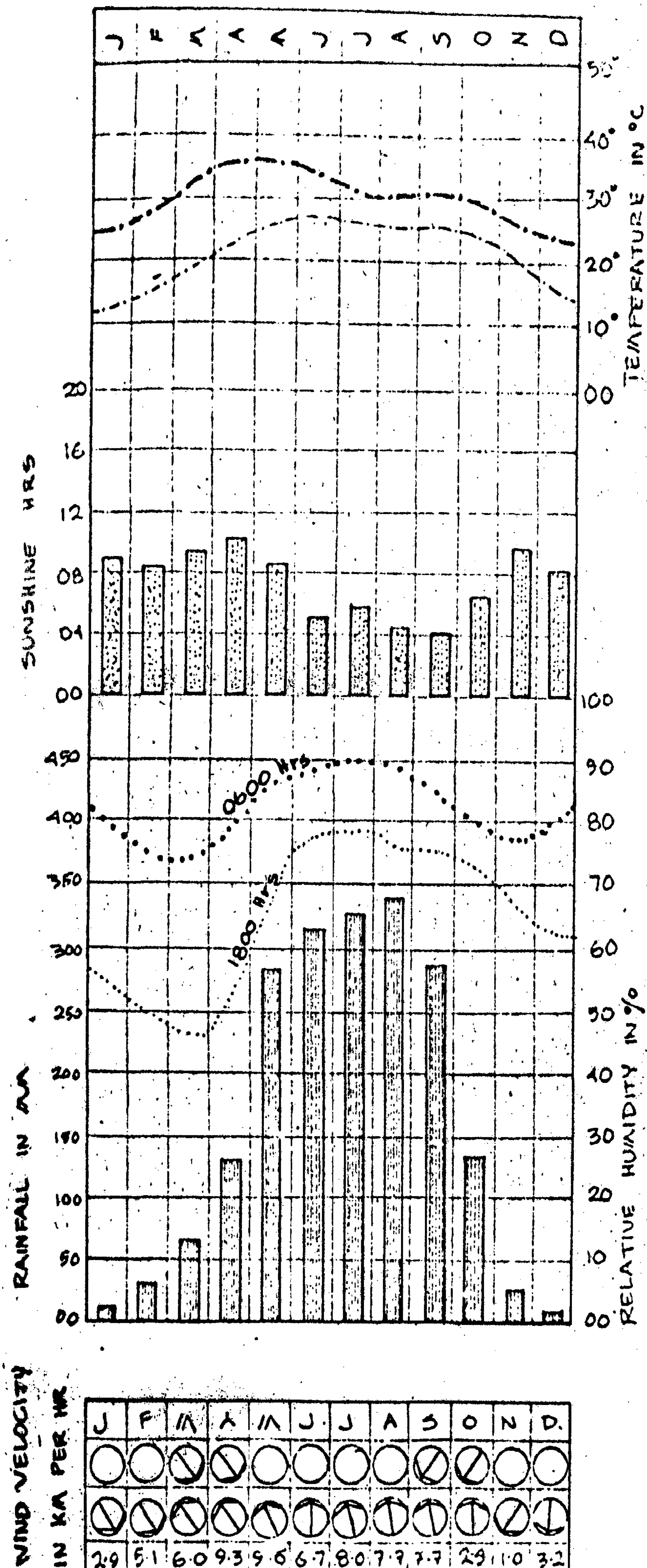
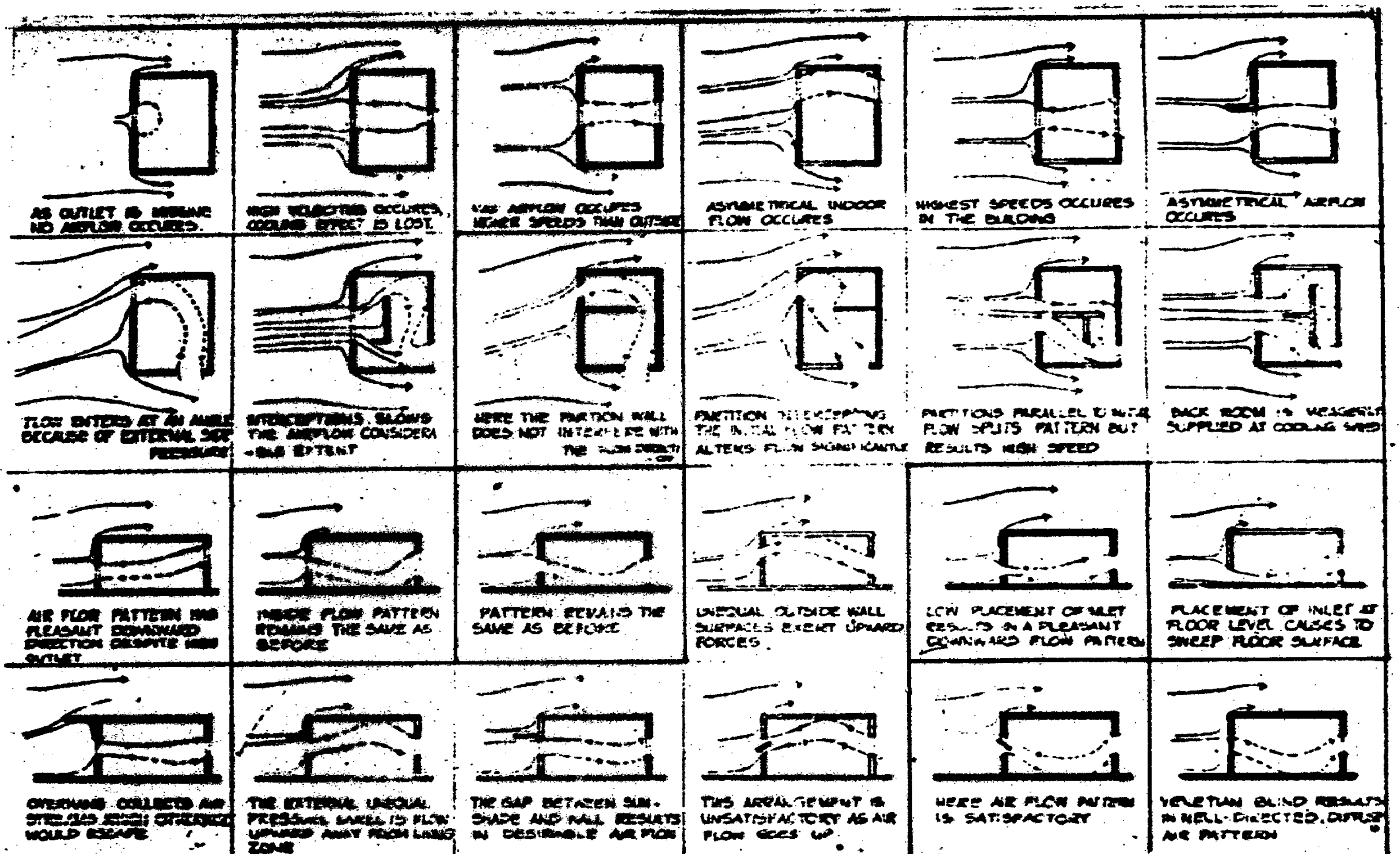


COUNTRY: BANGLADESH
LOCATION: DACCA
ALTITUDE: 9 M ABOVE SEA
LATITUDE: 23° 45' N
LONGITUDE: 90° 15' E

Appendix: 1
Summarize Climatic Data.

WIND VELOCITY IS MODERATE WITH THE EXCEPTION OF CYCLONIC WINDS IN SEPTEMBER AND OCTOBER AND NOR-WESTER IN APRIL WHICH MAY EXCEED 150 KM/HR.

Appendix : 2



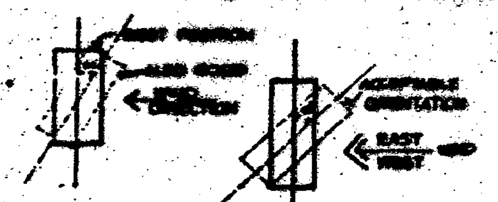
FLOW PATTERNS INSIDE BUILDINGS.

AP: 2·1 Air Flow Pattern Indoors -Vs - Location of Openings (12, 22, 29 & 41)

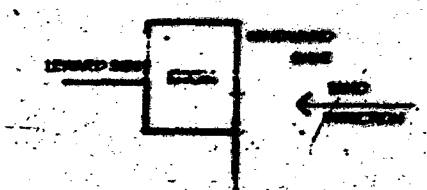
AIR MOTION IS AN IMPORTANT CONTRIBUTOR TO HUMAN THERMAL SENSATION. THE LEVEL OF ACCEPTABLE AIR MOTION DEPENDS UPON CLIMATIC CONDITIONS. IN HOT CLIMATES, HIGH RATES OF AIR MOTION ARE DESIRA FOR COMFORT AND PRIME IMPORTANCE IS GIVEN TO GOOD VENTILATION IN DESIGN OF BLDGS.

GUIDELINES FOR DESIGNING ANY BLDGS:

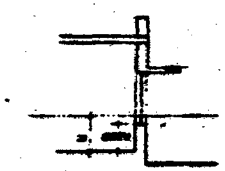
1. FOR ACHIEVING MAX. BENEFIT FROM NATURAL WIND, BUILDINGS NEED NOT NECESSARILY BE ORIENTED PERPENDICULAR TO THE PREVAILING OUTDOOR WIND. IT MAY BE ORIENTED AT ANY CONVENIENT ANGLE BETWEEN 0° AND 30° WITHOUT LOSING ANY BENEFICIAL ASPECT OF THE BREEZE. IF THE PREVAILING WIND IS FROM EAST OR WEST, BUILDINGS CAN BE ORIENTED AT 45° TO THE INCIDENT WIND FOR DIMINISHING THE SOLAR HEAT WITHOUT AFFECTING THE AIR MOTION INDOORS.



2. ATLEAST ONE WINDOW SHOULD BE PROVIDED ON THE WINDWARD WALL AND THE OTHER ON THE LEEWARD WALL.



3. MAX. AIR MOVEMENT AT A PARTICULAR PLANE IS ACHIEVED BY KEEPING THE SILL HEIGHT AT 85% OF THE HEIGHT OF THE PLANE(H)



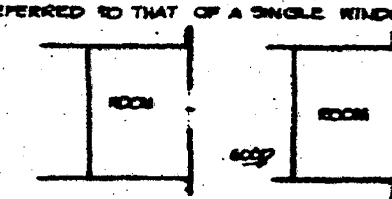
4. IN ROOMS OF NORMAL SIZE HAVING IDENTICAL WINDOWS ON OPPOSITE WALLS THE AVERAGE INDOOR AIR SPEED INCREASES RAPIDLY BY INCREASING THE WIDTH OF THE WINDOW UP TO ABOUT 2/3 OF THE WALL WIDTH; BEYOND THAT THE INCREASE IS IN MUCH SMALLER PROPORTION THAN THE INCREASE OF THE WINDOW WIDTH

5. THE AVERAGE INDOOR WIND SPEED IN THE WORK ZONE IS MAX. WHEN WINDOW HEIGHT IS 110 CMS. FURTHER INCREASE IN WINDOW HEIGHT PROMOTES AIR MOTION AT THE TOP LEVEL OF WINDOW, BUT DOES NOT CONTRIBUTE ADDITIONAL BENEFITS AS REGARDS AIR MOTION IN THE OCCUPANCY ZONE IN BUILDINGS.

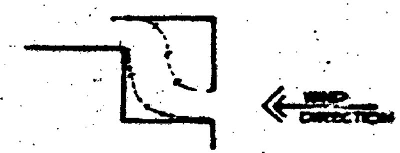
6. FOR TOTAL FENESTRATION AREA (INLET + OUTLET) OF 20 TO 30% OF FLOOR AREA, THE AVERAGE INDOOR WIND VELOCITY. FURTHER INCREASE IN WINDOW SIZE INCREASE THE AVAILABLE VELOCITY BUT NOT IN THE SAME PROPORTION. THE MAX AVERAGE INDOOR WIND VELOCITY DOES NOT EXCEED 40% OF THE OUTDOOR VELOCITY

7. IN REGIONS HAVING FAIRLY CONSTANT WIND DIRECTION, THE SIZE OF THE INLET SHOULD BE KEPT WITHIN 30 TO 50% OF THE TOTAL AREA OF FENESTRATION AND BUILDING SHOULD BE ORIENTED PERPENDICULAR TO THE INCIDENT WIND. SINCE INLETS SMALLER THAN OUTLETS ARE MORE SENSITIVE TO CHANGE IN WIND DIRECTION, OPENINGS OF EQUAL SIZES ARE PREFERRED IN THE REGIONS HAVING FREQUENT CHANGES IN WIND DIRECTION.

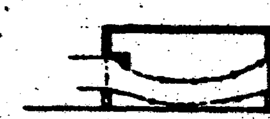
8. INCASE OF A ROOM WITH ONLY ONE WALL EXPOSED TO OUTSIDE, PROVISION OF TWO WINDOWS IS PREFERRED TO THAT OF A SINGLE WINDOW.



9. WINDOWS LOCATED DIAGONALLY OPPOSITE TO EACH OTHER, WITH THE WINDWARD WINDOW NEAR THE UPSTREAM CORNER, GIVE PERFORMANCE BETTER THAN OTHER WINDOW ARRANGEMENTS FOR MOST OF THE BLDG ORIENTATIONS.

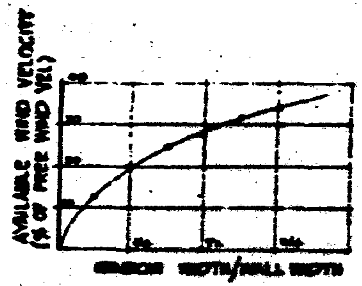


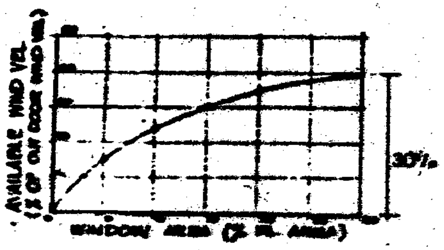
10. HORIZONTAL LOUVER (SUNSHADE) DEFLECTS THE INCIDENT WIND UPWARD AND REDUCES AIR MOTION IN THE ZONE OF OCCUPANCY. A GAP BETWEEN HORIZONTAL LOUVER AND WALL PREVENTS UPWARD DEFLECTION OF AIR IN THE INTERIOR OF ROOMS.



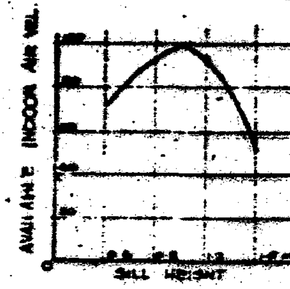
PROVISION OF L-TYPE LOUVERS INCREASES THE ROOM AIR MOTION PROVIDED THAT VERTICAL PROJECTION DOESNOT OBSTRUCT THE INCIDENT WIND.

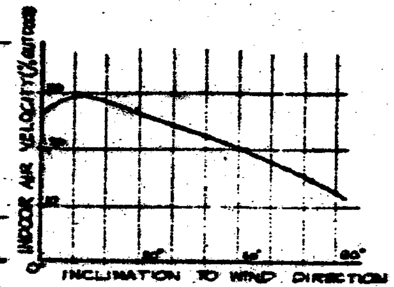
AP: 2-2 Orientation, Opening and wind pattern (12, 22, 29, & 41)





SILL HEIGHT →	[illegible]	[illegible]	[illegible]	1.5
HT. OF WORK PLANE [illegible]	21.5	25.2	24.9	13.9
[illegible]	22.2	25.9	21.2	14.4
[illegible]	24.9	23.7	17.8	12.7





HEIGHT OF WORK PLANE (M) / SILL HT.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	16.0	22.3	23.6	21.9	22.4	24.4	22.2	24.44
[illegible]	18.5	18.5	23.3	24.4	23.1	[illegible]	[illegible]	[illegible]
[illegible]	9.7	16.6	20.7	23.0	24.1	[illegible]	[illegible]	[illegible]
[illegible]	7.4	15.48	20.2	23.6	24.0	[illegible]	27.0	[illegible]
1.8	7.7	8.8	16.7	16.5	23.2	27.6	23.9	23.4
2.1	6.6	13.4	14.6	14.2	17.6	[illegible]	23.9	24.6

WINDOW LOCATION / OPENINGS →	0°	15°	30°	45°	60°	75°	90°
	23.6	24.8	22.3	18.0	16.3	12.5	10.0
	25.6	25.3	22.2	17.8	16.7	12.8	8.5
	21.4	18.2	16.3	15.6	13.5	11.4	8.6
	22.8	26.7	25.7	20.5	20.7	11.7	8.9
	22.5	23.8	25.0	26.7	20.4	11.7	10.5

WINDOW LOCATION / ORIENTATION →	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	22.48	16.12	3.80	10.78	16.48	22.6	22.48
	15.96	14.88	5.88	8.80	15.64	20.94	25.36
	21.36	14.48	3.36	8.28	10.16	17.24	22.92
	24.16	21.8	11.76	8.36	17.04	25.48	26.12
	23.6	20.7	10.08	8.28	13.48	21.60	27.04
	22.2	19.2	12.48	8.44	10.8	16.2	23.72
	22.8	23.96	17.36	10.04	17.48	23.8	23.72
	23.88	21.2	14.48	10.6	14.4	22.48	27.6
	22.2	20.6	17.44	10.04	13.36	18.64	24.16

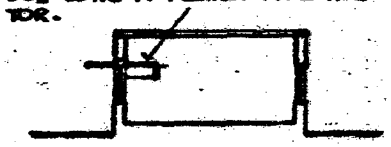
- THE OPENING, TOGETHER WITH ITS CONTROL DEVICES AS A COMPLETE UNIT, MUST SATISFY REQUIREMENTS OF
  - VENTILATION AND AIR MOVEMENT
  - CLOSURE FOR EXCLUSION OF AIR AT TIMES
  - DAYLIGHT ADMISSION AND GLARE CONTROL
  - SOLAR EXCLUSION
  - INSECTS, PESTS AND BURGLAR PROOFING
  - VIEW AND VISUAL EFFECTS

OF ALL ELEMENTS, OPENINGS GIVE PERHAPS THE MOST COMPLICATED AND DIFFICULT DESIGN TASK. CAREFUL CONSIDERATION AND WEIGHING OF THE REQUIREMENTS IS NECESSARY BEFORE ONE CAN PROCEED. INSTEAD OF TRYING TO DESIGN A WINDOW THAT FULFILS THE ABOVE SIX FUNCTIONS, ONE MIGHT PROVIDE FOUR SETS OF OPENINGS, ONE FOR DAYLIGHT, A SECOND FOR VIEW, A THIRD FOR AIR MOVEMENT, FOURTH FOR VENTILATION WITH ADEQUATE PROTECTION AGAINST DIRECT SOLAR RADIATION, BURGLARS & INSECTS.

AP:3 Location and Size of Opening -Vs- Breeze Indoors [12, 22, 29 & 41 ..]

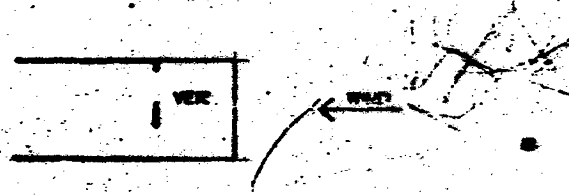
PROVISION OF HORIZONTAL SHASHES INCLINED AT AN ANGLE OF 45° IN APPROPRIATE DIRECTION HELPS TO PROMOTE THE AIR MOTION INSIDE ROOMS. SHASHES PROJECTING OUTWARD ARE MORE EFFECTIVE THAN PROJECTING INWARD.

AIR MOVEMENT AT WORKING PLANE 0.4 m ABOVE THE FLOOR CAN BE ENHANCED BY 30% USING A PLEMET TYPE WIND DEFLECTOR.



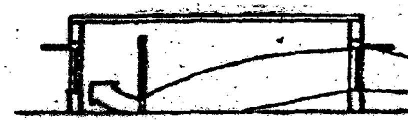
ROOF OVERHANGS HELP PROMOTING AIR MOTION IN THE WORKING ZONE INSIDE BUILDINGS.

VERANDAH OPEN ON THREE SIDES IS TO BE PREFERRED SINCE IT CAUSES AN INCREASE IN THE ROOM AIR MOTION FOR MOST OF THE ORIENTATIONS OF BUILDING WITH RESPECT TO THE INCIDENT WIND.

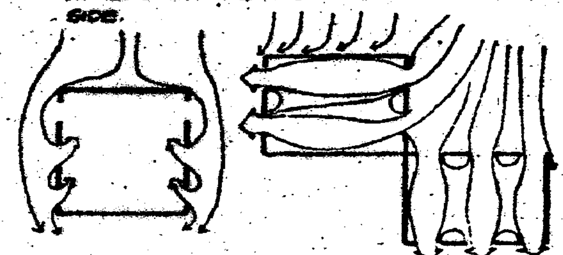


A PARTITION PLACED PARALLEL TO THE INCIDENT WIND, HAS LITTLE INFLUENCE ON THE PATTERN OF AIR FLOW; BUT WHEN LOCATED PERPENDICULAR TO THE MAIN-FLOW, THE SAME PARTITION CREATES

A WIND SHADOW. PROVISION OF A PARTITION WITH SPACING OF 0.3 M UNDERNEATH, HELPS MAKING AIR MOTION NEAR FLOOR LEVEL IN THE LEEWARD COMPARTMENT OF WIDE SPAN BUILDINGS.



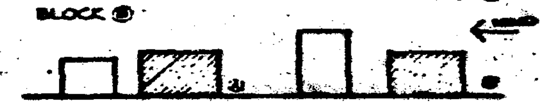
16. AIR MOTION IN A BUILDING UNIT HAVING WINDOWS TANGENTIAL TO THE INCIDENT WIND IS ACCELERATED WHEN ANOTHER UNIT IS LOCATED AT END-ON POSITION ON DOWNSTREAM SIDE.



17. AIR MOTION IN TWO WINGS ORIENTED PARALLEL TO THE PREVAILING BREEZE IS PROMOTED BY CONNECTING THEM WITH A BLOCK ON THE DOWNSTREAM SIDE.

AIR MOTION IN A BUILDING IS LESS THAN THAT IN AN UNOBSTRUCTED BUILDING. TO MINIMISE SHIELDING EFFECT, THE DISTANCE BETWEEN THE TWO ROWS SHOULD BE ABOUT 8 H FOR SEMIDETACHED HOUSES AND 10 H FOR A LONG ROWS HOUSES. HOWEVER, THE SHIELDING EFFECT IS DIMINISHED BY RAISING THE HEIGHT OF THE SHIELDED BUILDING.

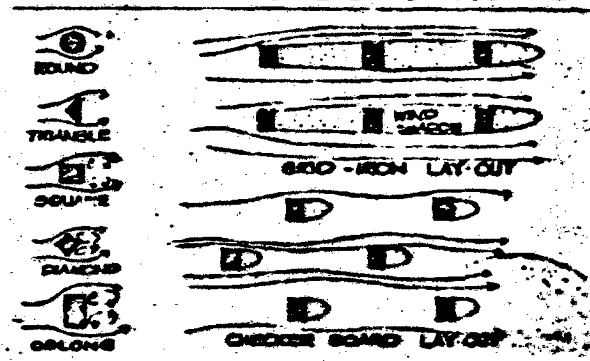
AIR MOTION IN A BUILDING IS NOT AFFECTED BY CONSTRUCTING ANOTHER BUILDING OF EQUAL OR SMALLER HEIGHT ON THE LEEWARD SIDE; BUT IT IS SLIGHTLY REDUCED IF LEEWARD BUILDING IS TALLER THAN THE WINDWARD BLOCK.



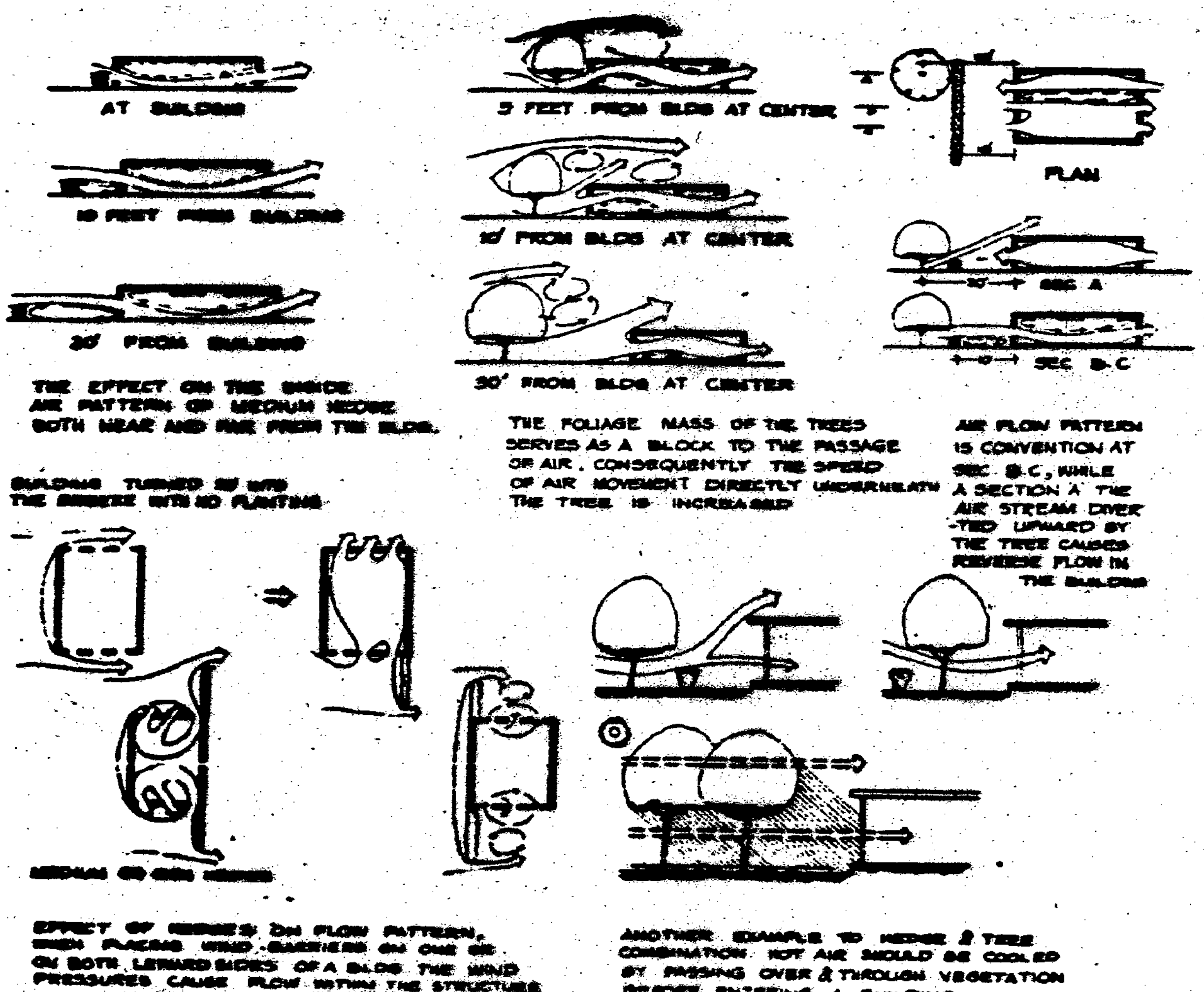
10. HEDGES AND SHRUBS DEFLECT THE AIR AWAY FROM THE INLET OPENING AND CAUSE A REDUCTION IN AIR MOTION INDOORS. AIR MOTION IN THE LEEWARD PART OF THE BUILDING CAN BE ENHANCED BY PLANTING A LOW HEDGES AT A DISTANCE OF 2 m FROM THE BUILDING.

TREES WITH LARGE FOLIAGE MASS HAVING TRUNK BARE OF BRANCHES UP TO THE TOP LEVEL OF WINDOW, DEFLECT THE OUTDOOR WIND DOWNWARDS AND PROMOTES AIR MOTION IN THE OCCUPANCY ZONE INSIDE THE BUILDINGS.

12. VENTILATION CONDITIONS INDOORS CAN BE AMELIORATED BY CONSTRUCTING BUILDINGS ON EARTH MOUND HAVING A SLANT SURFACE WITH A SLOPE OF 10° ON UPSTREAM SIDE.



:4 Layout planning and Wind pattern [12, 22, 29 & 41.]



AP:5 Effect of Landscape on Air Flow [12,22,29 & 41.]

EFFECT OF LANDSCAPE ON AIRFLOW

THE VARIOUS LANDSCAPE ELEMENTS SURROUNDING LOW STRUCTURES CAN HAVE DEFINITE EFFECTS BOTH ON AIRFLOW PATTERNS AND ON WIND VELOCITIES. TREES AND SHRUBS, WALLS AND FENCE, ALL CREATE HIGH AND LOW PRESSURE AREAS AROUND A DWELLING IN RELATION TO THE POSITION OF OPENINGS IN WALLS. TREES AND VEGETATION CAN BE USED TO DIRECT BENEFICIAL AIR MOTION INTO BUILDINGS. CARE SHOULD BE TAKEN TO AVOID LOCATING TREES AND VEGETATION, WHERE THEY MIGHT ELIMINATE DESIRABLE COOLING BREEZE DURING THE OVERHEATED PERIODS. THE POSITION AND SIZE OF THE VEGETATION CAN HAVE A MARKED EFFECT ON THE MOVEMENT OF AIR OVER AND AROUND LOW BLDGS. AIRFLOW PATTERNS CAN BE MODIFIED BY LANDSCAPING, AS LONG AS IT DOES NOT RESTRICT THE FREE FLOW OF THE BREEZE.

Appendix : 6

TABLE 1

Location	Dhaka
Longitude	90° 15′
Latitude	23° 45′
Altitude	10 m.

Air temperature: °C

	J	F	M	A	M	J	J	A	S	O	N	D		
													High	AMT
Monthly mean max.	25·8	27·3	31·1	34·1	30·8	31·9	32·4	33·0	30·8	31·8	24·8	25·7	34·1	25·2
Monthly mean min.	12·3	18·5	19·8	23·3	24·9	26·0	26·3	26·6	25·6	25·6	18·6	14·4	12·3	21·8
Monthly mean range	13·5	8·8	11·3	10·8	5·9	5·9	6·1	6·4	5·2	8·2	6·2	11·3	Low	AMR

Relative humidity: %

	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max. a.m.	91	90	87	92	93	94	95	93	93	82	83	90
Monthly mean min. p.m.	60	49	51	67	77	76	83	81	82	66	65	64
Average	75·5	69·5	69	79·5	85	85	89	87	87·5	74	74	77
Humidity group	4	3	3	4	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	3	15	81	104	354	416	356	187	320	82	18	30	[illegible]

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

		AMT over 20°C		AMT 15–20°C		AMT below 15°C	
Comfort limits		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.	25·8	27·3	31·1	34·1	30·8	31·9	32·4	33·0	30·8	31·8	24·8	25·7	21..
Day comfort: upper	27	29	29	27	27	27	27	27	27	27	27	27	
lower	22	23	23	22	22	22	22	22	22	22	22	22	
Monthly mean min.	12·3	18·5	19·8	23·3	24·9	26·0	26	26·6	25·6	23·6	18·6	14·9	
Night comfort: upper	21	23	23	21	21	21	21	21	21	21	21	21	
lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress: day	O	O	H	H	H	H	H	H	H	H	O	O	
night	C	O	O	H	H	H	H	H	H	H	O	C	

Indicators

		J	F	M	A	M	J	J	A	S	O	N	D	Totals
Humid:	H1			✓	✓	✓	✓	✓	✓	✓	✓			8
	H2	✓	✓									✓	✓	4
	H3					✓	✓	✓		✓				4
Arid:	A1													0
	A2													0
	A3													0

		Applicable when				
		Thermal stress				
Meaning	Indicator	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
8	4	4	0	0	0

TABLE 3
Recommended specifications

Layout

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

Openings

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

Roofs

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

Rain protection

H1	H2	H3	A1	A2	A3	✓	No.	Specification
		3–12				✓	17	Protection from heavy rain necessary

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
8	4	4	0	0	0

TABLE 4

Detail recommendations

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
								Size of opening
			0, 1		0	✓	1	Large: 40–80%
			0, 1		1–12		2	Medium: 25–40%
			2–5				2	
			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	
1–2			6–12				7	As above, openings also in internal walls
0	2–12						7	
								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	
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

Appendix: 7

Duration of Solar radiation received on the facade-vs- variation in the angle of orientation of the facade.

Angle of orientation of facade	Duration of solar radiation received on June 22	Sept.23 March 21	Dec.22
00/360	SR to S.S	-	-
45	SR to 12 noon	SR to 10:30AM	SR to 9AM
90	SR to 12 noon	SR to 12 noon	SR to 12 noon
135	SR to 12 noon	SR to 1.25PM	SR to 2.50PM
180	-	SR to S.S	SR to SS
225	12 noon to SS	10.30AM to SS	9AM to SS
270	12 noon to SS	12 noon to SS	12 noon to SS
315	12 noon to SS	1.25PM to SS	2.50PM to SS

SR = Sun rise, SS = Sun set. See Fig.29

Appendix: 8

Intensity of Solar radiation received on the facade- vs-variation in the angle of orientation of the facade

The Day	Orientation (deg.)	Radiation received at the instants(W/m2) Mid Morning			Mid day			Mid afternoon		
		Direct	Diffuse	Total	Direct	Diffuse	Total	Direct	Diffuse	Total
June 22	00/360	100	55	155	00	90	90	100	55	155
	45	500	95	595	00	90	90	00	50	50
	90	550	100	650	00	90	90	00	50	50
	135	325	80	405	00	90	90	00	50	50
	180	00	50	50	00	90	90	00	50	50
	225	00	50	50	00	90	90	325	80	405
	270	00	50	50	00	90	90	550	100	650
	315	00	50	50	00	90	90	500	95	595
Sept 23 and May 21	00/360	00	50	50	00	80	80	00	50	50
	45	250	70	320	00	80	80	00	50	50
	90	550	100	650	00	80	80	00	50	50
	135	550	100	650	250	95	345	00	50	50
	180	250	70	320	320	95	415	250	70	320
	225	00	50	50	250	95	345	550	100	650
	270	00	50	50	00	80	80	550	100	650
	315	00	50	50	00	80	80	250	70	320
Dec. 22	00/360	00	30	30	00	50	50	00	30	30
	45	00	30	30	00	50	50	00	30	30
	90	400	70	470	00	50	50	00	30	30
	135	600	100	700	400	90	490	00	30	30
	180	450	70	520	575	100	675	450	70	520
	225	00	30	30	400	90	490	600	100	700
	270	00	30	30	00	50	50	400	70	470
	315	00	30	30	00	50	50	00	30	30

See Fig.30

Appendix:9

Degree of coverage of the indoor space by the penetrating beam of sun light-vs-variation in the width and height of the opening and the angle of orientation of the facade.

The day	orien-tation (deg)	Instants of the day: Mid-morning				Mid-day				and-afternoon			
			α	cos	cotα		α	cos	cotα		α	cos	cot α
June 22	00/360	77^{+}	74	0.23	0.29					77^{-}	74	0.23	0.29
	45	32^{+}	45	0.85	1.0								
	90	10^{-}	42	0.98	1.11								
	135	57^{-}	58	0.54	0.62								
	180												
	225									57^{+}	58	0.54	0.62
	270									10^{+}	42	0.98	1.11
	315									35^{-}	45	0.85	0.29
Sept. 23 and May 21	00/360												
	45	66^{+}	69	0.41	0.49								
	90	20^{+}	43	0.94	1.07	90^{+}	90	0.00	0.0				
	135	23^{-}	45	0.92	1.00	45^{+}	72	0.71	0.32				
	180	70^{-}	67	0.34	0.42	00	67	1.0	0.4	70^{+}	67	0.34	0.42
	225					45^{-}	72	0.71	0.3	23^{+}	45	0.92	1.0
	270					90^{-}	90	0.0	0.0	20^{-}	43	0.94	1.07
	315									66^{-}	64	0.41	0.44
Dec. 22	00/360												
	45												
	90	48^{+}	38	0.67	1.33	90^{+}	90	0.00	0.0				
	135	03^{+}	37	0.99	1.73	45^{+}	50	0.71	0.8	88^{+}	85	0.03	0.09
	180	44^{-}	36	0.72	1.38	00	44	1.00	1.0	44^{+}	36	0.72	1.38
	225	88^{-}	85	0.03	0.09	45	50	0.71	0.8	03^{-}	30	0.99	1.73
	270					90^{-}	90	0.00	0.0	48^{-}	37	0.67	1.33
	315												

\+ measured clockwise on the shadow angle protractor

\- measured anticlockwise on the shadow angle protractor

Note: See Fig:31 and 32.

Degree of exposure of facade (in terms of surface area) to solar radiation-vs-variation in spacing

The day	Instants of day	Sun's Azimuth (z)	Sun's Altitude (h)	length of the shadow H cot α	Direction of shadow
June 22	Mid-Mor.	79	95	1.0 H	W 11°S
	Mid-day	180	90	o.0	-
	Mid-aft.	281	45	1.0 H	E 11°S
Sep. 23 and May. 21	Mid-Mor.	112	42	1.11 H	W 22°N
	Mid-day	180	66	0.44 H	N
	Mid-aft.	248	42	1.11 H	E 22°N
Dec. 22	Mid-mor.	138	30	1.73 H	W 48°N
	Mid-day	180	43	1.07 H	N
	Mid-aft.	222	30	1.73 H	E 48°N

Note: See Fig. 12,25, 33 and 34.

Appendix-11.1

Exposure of facade to solar radiation-vs- variation in depth of staggering and contilever.

The day	Orientation (deg.)	Instants of the day								
		Mid. mor.			Mid-day			Mid.aft.		
		Tanθ	tanα	cotα	tanθ	tanα	cotα	tanθ	tanα	cot α
June 22	00	4.33	3.49	0.29	-	-	-	4.33	3.49	0.29
	45	0.62	1.00	1.00	-	-	-	-	-	-
	90	0.18	0.90	1.11	-	-	-	-	-	-
	135	1.54	1.60	0.62	-	-	-	-	-	-
	180	-	-	-	-	-	-	-	-	-
	225	-	-	-	-	-	-	1.54	1.60	0.62
	270	-	-	-	-	-	-	0.18	0.90	1.11
	315	-	-	-	-	-	-	0.62	1.00	1.00
Sep. 23 and Mar. 21	00	-	-	-	-	-	-	-	-	-
	45	2.25	2.05	0.49	-	-	-	-	-	-
	90	0.36	0.93	1.07	∞	∞	00	-	-	-
	135	0.42	1.00	1.00	[illegible].0	3.08	0.32	-	-	-
	180	2.75	2.35	0.42	000	2.35	0.42	2.75	2.35	0.42
	225	-	-	-	[illegible].0	3.08	0.32	0.42	1.00	1.00
	270	-	-	-	∞	∞	0.00	0.36	0.93	1.07
	315	-	-	-	-	-	-	2.25	2.05	1.49
	00	-	-	-	-	-	-	-	-	-
	45	-	-	-	-	-	-	-	-	-
	90	1.11	0.75	1.33	[illegible]	∞	00	-	-	-
	135	0.05	0.58	1.73	1.[illegible]	1.19	0.84	28.64	11.43	0.09
	180	0.96	0.93	1.38	0.[illegible]	0.96	1.04	0.96	0.73	1.38
	225	28.54	11.4	0.09	1.[illegible]	1.19	0.84	0.05	0.58	1.73
	270	-	-	-	∞	∞	0.0	1.11	0.75	1.33
	315	-	-	-	-	-	-	-	-	-

Refer to Appemdix 11.2

Appendix:11.2

Degree of exposure of facade to solar irradiation at the required instants of the day-vs-orientation.

The day	Orientation (deg)	Degree of exposure of facade on								
		Mid-morning			Mid-day			mid-afternoon		
		Critical'd'	X	Y	Critical'd'	X	Y	Critical'd'	X	Y
Jun 22	00/360	0.29 H	4.43d	3.49d						
	45	1.0 H	0.62d	1.0 d						
	90	1.11 H	0.18d	0.9 d						
	135	0.62 H	1.54d	1.6 d						
	180	-	-	-				-	-	-
	225							0.62 H	1.54d	1.6 d
	270							1.11 H	0.18d	0.9 d
	315							1.0 H	0.62d	1.0 d
Sep. 23 and Mar. 21	00/360									
	45	0.49 H	2.25d	2.05d						
	90	1.07 H	0.36d	0.93d	00	∞	∞			
	135	1.0 H	0.42d	1.0 d	0.32H	1.0d	3.08d			
	180	.42 H	2.75d	2.35d	0.42H	0d	2.35d	0.42H	2.75d	2.35d
	225				0.32H	1.0d	3.08d	1.0 H	0.42d	1.0 d
	270				0.0	∞	∞	1.07H	0.36d	0.93d
	315							0.49H	2.75d	2.05d
Dec. 22	00/360									
	45									
	90	1.33 H	1.11d	0.75d	0.0	∞	∞			
	135	1.73 H	0.05d	0.58d	0.84H	1.0d	1.19d	0.09H	28.64d	11.45d
	180	1.38 H	0.96d	0.73d	1.04H	0.0	0.96d	1.38H	0.96d	0.73d
	225	0.09H	11.43d	0.84d	0.84H	1.0d	1.19d	1.73H	0.05d	0.58d
	270				0.0	∞	∞	1.33H	1.11d	0.75d
	315									

Refer to Appendix 11,1.
Note: See Fig: 33 and 35.

Appendix: 12.

-THERMAL FACTORS FOR STANDARD CONSTRUCTION

EXTERNAL WALLS Surface resistance: external = 0·055 m^2 °C/W, Internal = 0·123 m^2 °C/W

Description	Density (kg/m^3)	Conductivity (W/m °C)	Specific heat (J/kg °C)	*U* value (W/m^2 °C)	Admittance		Decrement		Surface factor	
					Y(W/m^2°C)	ϕ_Y(hours)	*f*	ϕ_f(hours)	*F*	ϕ_F(hours)
BRICKWORK										
1. Solid brickwork, unplastered Brick 105 mm	1700	0·84	800	3·3	4·2	1·2	0·88	2·5	0·54	1·2
2. Solid brickwork, unplastered Brick 220 mm	1700	0·84	800	2·3	4·6	1·5	0·54	6·0	0·52	1·6
3. Solid brickwork, unplastered Brick 335 mm	1700	0·84	800	1·7	4·7	1·4	0·29	9·4	0·51	1·6
4. Solid brickwork with dense plaster Brick 105 mm Dense plaster 16 mm	1700 1300	0·84 0·50	800 1000	3·0	4·1	1·3	0·83	3·0	0·56	1·2
5. Solid brickwork with dense plaster Brick 220 mm Dense plaster 16 mm	1700 1300	0·84 0·50	800 1000	2·1	4·4	1·4	0·49	6·5	0·53	1·4
6. Solid brickwork with dense plaster Brick 335 mm Dense plaster 16 mm	1700 1300	0·84 0·50	800 1000	1·7	4·4	1·4	0·26	9·9	0·53	1·4
7. Solid brickwork with light weight plaster Brick 105 mm Lightweight plaster 16 mm	1700 600	0·84 0·16	800 1000	2·5	3·1	1·0	0·82	3·1	0·64	0·6
8. Solid brickwork, with lightweight plaster Brick 220 mm Lightweight plaster 16 mm	1700 600	0·84 0·16	800 1000	1·9	3·4	1·1	0·45	6·7	0·62	0·8
9. Solid brickwork with lightweight plaster Brick 335 mm Lightweight plaster 16 mm	1700 600	0·84 0·16	800 1000	1·5	3·4	1·1	0·23	10·0	0·62	0·7
10. Solid brickwork with plaster board Brick 220 mm Plasterboard 10 mm	1700 950	0·84 0·16	800 840	1·9	3·4	1·2	0·45	6·7	0·61	0·8
CAVITY WALLS (UNVENTILATED)										
11. Cavity wall with 105 mm inner and outer brick leaves with dense plaster on inner Brick 105 mm Cavity 20 mm Brick 105 mm Dense plaster 16 mm	1700 resistance 1700 1300	0·84 = 0·18 0·62 0·50	800 m^2 °C/W 800 1000	1·5	4·3	1·7	0·43	7·8	0·57	1·6

Description	Density (kg/m³)	Conductivity (W/m °C)	Specific heat (J/kg °C)	U value (W/m² °C)	Admittance		Decrement		Surface factor	
					Y (W/m² °C)	φY (hours)	f	φf (hours)	F	φF (hours)
12. Cavity wall as 11 but with lightweight plaster										
Brick 105 mm	1700	0·84	800							
Cavity >20 mm	resistance = 0·18 m² °C/W			1·3	3·3	1·4	0·39	8·0	0·64	0·9
Brick 105 mm	1700	0·62	800							
Lightweight plaster 16 mm	600	0·50	1000							
13. Cavity wall as 11 but with 230 mm outer leaf										
Brick 230 mm	1700	0·84	800							
Cavity >20 mm	resistance = 0·18 m² °C/W			1·2	4·3	1·7	0·20	11·7	0·57	1·8
Brick 105 mm	1700	0·62	800							
Dense plaster 16 mm	1300	0·50	1000							
14. Cavity wall as 13 but with lightweight plaster										
Brick 230 mm	1700	0·84	800							
Cavity >20 mm	resistance = 0·18 m² °C/W			1·1	3·3	1·4	0·18	11·8	0·64	0·9
Brick 105 mm	1700	0·62	800							
Lightweight plaster 16 mm	600	0·16	1000							
15. Cavity wall with brick outer and lightweight concrete block inner with dense plaster on inner										
Brick 105 mm	1700	0·84	800							
Cavity >20 mm	resistance = 0·18 m² °C/W									
Lightweight concrete block 100 mm	600	0·19	1000	0·96	2·9	2·7	0·56	7·1	0·77	1·2
Dense plaster 16 mm	1300	0·50	1000							
16. Cavity wall as 15 but with 13 mm expanded polystyrene in cavity										
Brick 105 mm	1200	0·84	800							
Cavity >20 mm	resistance = 0·18 m² °C/W									
Polystyrene 13 mm	25	0·033	1380	0·70	3·0	2·8	0·49	8·0	0·77	1·3
Lightweight concrete block 100 mm	600	0·19	1000							
Dense plaster 16 mm	1300	0·50	1000							
17. Cavity wall, rendered externally with 75 mm aerated concrete block outer and 100 mm aerated concrete inner with dense plaster on inner										
Rendering 10 mm	1300	0·50	1000							
Aerated concrete block 75 mm	750	0·24	1000							
Cavity >20 mm	resistance = 0·18 m² °C/W			0·85	3·2	2·5	0·54	7·2	0·73	1·3
Aerated concrete block 100 mm	750	0·22	1000							
Dense plaster 16 mm	1300	0·50	1000							
CONCRETE										
18. Solid cast concrete 150 mm thick										
Concrete 150 mm	2100	1·40	840	3·5	5·2	1·2	0·71	3·9	0·44	1·8
19. Solid cast concrete 200 mm thick										
Concrete 200 mm	2100	1·40	840	3·1	5·4	1·2	0·57	5·3	0·42	2·0
20. Pre-cast panel 25 mm thick										
Concrete 75 mm	2100	1·40	840	4·3	4·9	0·8	0·92	1·8	0·43	1·2
21. Cast concrete (150 mm) with 50 mm wood wool slab on inner surface finished with 16 mm dense plaster										
Concrete 150 mm	2100	1·40	840							
Wood wool 50 mm	500	0·10	1000	1·2	2·3	2·5	0·50	6·5	0·80	0·8
Dense plaster 16 mm	1300	0·50	1000							

Description		Density (kg/m³)	Conductivity (W/m °C)	Specific heat (J/kg °C)	U value (W/m² °C)	Admittance		Decrement		Surface factor	
						Y (W/m² °C)	ϕ_Y (hours)	f	ϕ_f (hours)	F	ϕ_F (hours)
22. As 21 but with 200 mm concrete											
Concrete	200 mm	2100	1·40	840	1·2	2·3	2·5	0·16	7·8	0·79	0·8
Wood wool	50 mm	500	0·10	1000							
Dense plaster	16 mm	1300	0·50	1000							
23. 75 mm concrete panel with inner sandwich panel of 5 mm asbestos cement sheet, 25 mm expanded polystyrene and 10 mm plaster board											
Concrete	75 mm	2100	1·40	840	0·80	1·00	2·00	0·82	3·1	0·90	0·3
Cavity	20 mm	resistance = 0·18 W/m² °C									
Asbestos cement sheet	5 mm	700	0·36	1050							
Expanded polystyrene	25 mm	25	0·033	1380							
Plaster board	10 mm	950	0·16	840							
24. Pre-cast sandwich consisting of 75 mm dense concrete, 25 mm expanded polystyrene and 150 mm lightweight concrete											
Concrete	75 mm	2100	1·40	840	0·72	3·8	1·8	0·28	9·8	0·62	1·3
Expanded polystyrene	25 mm	25	0·033	1380							
Lightweight concrete	150 mm	1200	0·38	1000							

THERMAL FACTORS FOR STANDARD CONSTRUCTION

ROOFS

Surface resistance: external = 0·045 m² °C/W; internal = 0·123 m² °C/W

Description		Density (kg/m³)	Conductivity (W/m °C)	Specific heat (J/kg °C)	U value (W/m² °C)	Admittance		Decrement		Surface factor	
						Y (W/m² °C)	ϕ_Y (hours)	f	ϕ_f (hours)	F	ϕ_F (hours)
1. Asphalt 15 mm on lightweight concrete screed 75 mm on dense concrete 150 mm											
Asphalt	15 mm	1700	0·50	1000	1·9	5·1	1·1	0·36	7·4	0·44	1·60
Screed	75 mm	1200	0·41	840							
Dense concrete	150 mm	2100	1·40	840							
Dense plaster	15 mm	1300	0·50	1000							
2. Asphalt 19 mm on 150 mm autoclaved aerated concrete roof slabs with dense plaster internally											
Asphalt	19 mm	1700	0·50	1000	0·86	2·5	3·0	0·78	4·7	0·81	1·0
Aerated concrete	150 mm	500	0·16	840							
Dense plaster	15 mm	1300	0·50	1000							
3. Asphalt 19 mm on fibre insulation board 13 mm on hollow or cavity asbestos cement decking											
Asphalt	19 mm	1700	0·50	1000	1·5	1·9	1·9	0·96	1·8	0·80	0·6
Fibre board	13 mm	300	0·057	1000							
Asbestos cement	10 mm	1500	0·36	1000							
Cavity	55 mm	resistance = 0·18 m² °C/W									
Asbestos cement	10 mm	1500	0·36	1000							

Description	Density (kg/m³)	Conductivity (W/m °C)	Specific heat (J/kg °C)	U value (W/m² °C)	Admittance Y (W/m² °C)	Admittance ϕy (hours)	Decrement f	Decrement ϕf (hours)	Surface factor F	Surface factor ϕF (hours)
4. Asphalt 19 mm on 13 mm cement and sand screed on 50 mm wood wool slabs on steel framing with cavity and 10 mm plaster board ceiling										
Asphalt 19 mm	1700	0·50	1000							
Cement and sand 13 mm	2100	1·28	1000							
Wood wool slab 50 mm	560	0·10	1000	1·03	1·45	2·1	0·89	3·0	0·85	0·4
Cavity 100 mm	resistance=0·18 m² °C/W									
Plaster board 10 mm	950	0·16	1000							
5. Felt/Bitumen layers on 25 mm expanded polystyrene on metal decking										
Felt/Bitumen 19 mm	1700	0·50	1000	1·03	1·0	0·1	0·99	0·6	0·87	0·0
Expanded polystyrene 25 mm	25	0·033	1000							

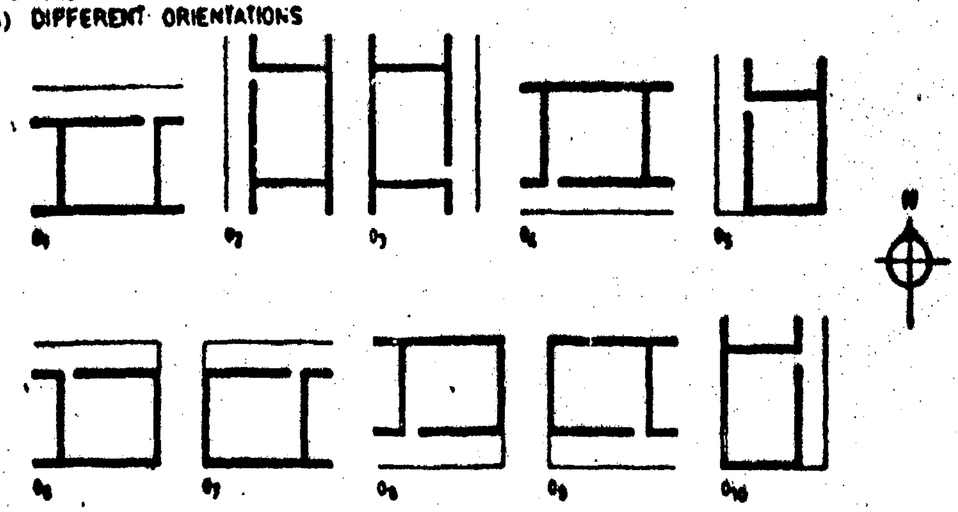
THERMAL FACTORS FOR STANDARD CONSTRUCTION

INTERNAL WALLS Surface resistance 0·123 m² °C/W

Description	Density (kg/m³)	Conductivity (W/m °C)	Specific heat (J/kg °C)	U value (W/m² °C)	Admittance		Decrement		Surface factor	
					Y (W/m² °C)	ϕy (hours)	f	ϕf (hours)	F	ϕF (hours)
1. Lightweight concrete block plastered both sides										
Dense plaster 15 mm	1300	0·50	1000							
Lightweight concrete block 75 mm	600	0·19	840	—	1·2	2·2	—	—	0·92	1·2
Dense plaster 15 mm	1300	0·50	1000							
2. Half brick plastered both sides										
Dense plaster 15 mm	1300	0·50	1000							
Brick 105 mm	1700	0·84	800	—	3·3	0·4	—	—	0·71	2·2
Dense plaster 15 mm	1700	0·50	1000							
3. Cast concrete plastered both sides										
Dense plaster 12 mm	1300	0·50	1000							
Concrete 65 mm	1200	0·41	1000	—	2·0	0·7	—	—	0·84	1·7
Dense plaster 12 mm	1300	0·50	1000							
4. Two fibre board sheets with cavity between them										
Fibre board 12 mm	300	0·057	1000							
Cavity >20 mm	resistance=0·18 m² °C/W			—	0·06	3·2	—	—	1·00	0·1
Fibre board 12 mm	300	0·057	1000							

Appendix: 13·1

a) DIFFERENT ORIENTATIONS



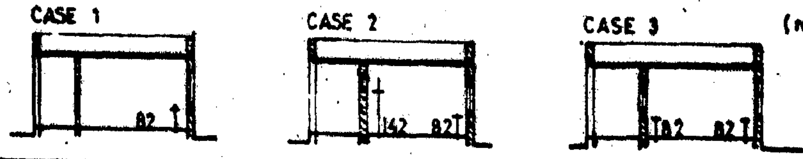
b) TYPE OF WINDOW

TYPE OF WINDOW	SIZE (cm²)	SYMBOL
———————	75 x 135	X
—·—·—·—	105 x 135	Y
- - - - - - - -	135 x 135	Z

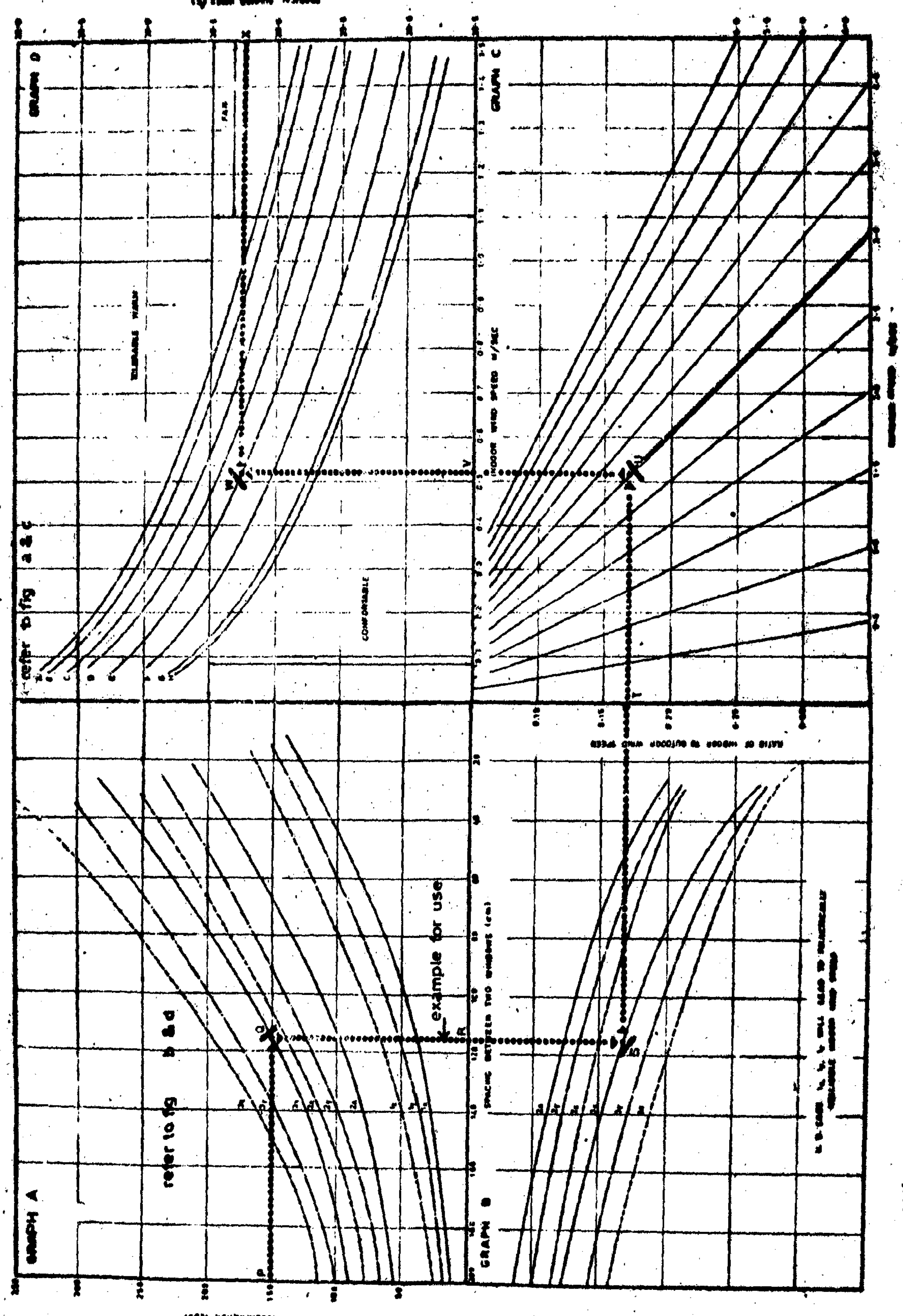
c) DETAILS OF ORIENTATIONS, ROOF EXPOSED & EXPOSED WALL FINISHING (refer a)

GROUP	PLANS AS ABOVE		ROOM LOCATION	EXPOSED SURFACE COLOUR
a	▷	O3	ROOF EXPOSO	DARK
		O7	ROOF EXPOSED	"
		O10	ROOF EXPOSED	"
b	▷	O2	ROOF EXPOSED	"
		O6	ROOF EXPOSED	"
		O5	ROOF EXPOSED	"
c	▷	O4	ROOF EXPOSED	"
		O1	ROOF EXPOSED	"
		O8	RCOF EXPOSED	"
		O3	ROOF EXPOSED	LIGHT
d	▷	O2	ROOF EXPOSED	"
		O6	ROOF EXPOSED	"
		O9	ROOF EXPOSED	"
e	▷	O1	ROOF EXPOSED	"
		O4	ROOF EXPOSED	"
		O9	ROOF EXPOSED	"
f	▷	O10	ROOF SHADED	DARK
		O7	ROOF SHADED	"
g	▷	O3	ROOF SHADED	LIGHT
		O7	ROOF SHADED	"
h	▷	O6	ROOF SHADED	"
		O1	ROOF SHADED	"

d) CASE 1 CASE 2 CASE 3 (refer b)



AP. 13·1. Key to Window Design Nomogram [32]



AP.13.2 Window Design Nomogram [refer to fig-

Appendix: 14.

Shading coefficients for different combinations of glasses and glass and various shading devices so adjusted as to exclude direct sun penetration except where otherwise stated (34)

Method of shading	Description	Shading coefficient	Source of information
Double glazing	Ordinary clear glass (solar transmittance 0·86) both sides	0·90	ASHRAE Guide and Data Book: Fundamentals and Equipment, 1965/6
	Heat-absorbing glass (solar transmittance 0·46) outside and plate glass (solar transmittance 0·80) inside	0·56	ditto
	Solarshield UV 393 I.R. 2/20 outside and ordinary clear glass inside. Air space ventilated to outside	0·17	National Building Research Institute, Pretoria
Internal shading	Ordinary glass with venetian blind: light coloured medium coloured	0·55 0·64	ASHRAE Guide and Data Book: Fundamentals and Equipment, 1965/6
	Ordinary glass with opaque roller shade: white dark coloured	0·25 0·59	ditto
	Ordinary glass with curtains or draperies: light, closed weave dark, closed weave	0·44 0·62	ditto
Between-glass shading	Ordinary glass both sides and venetian blind in between: white medium coloured	 0·33 0·36	ditto
External shading	Ordinary glass shaded with miniature louvres (Koolshade) dark coloured: 17 louvres/in. 23 louvres/in.	0·49–0·13* 0·41–0·09*	National Building Research Institute, Pretoria
	Ordinary glass shaded completely with awnings, louvres, etc., and allowing free air movement	0·20	ditto and ASHRAE Guide and Data Book: Fundamentals and Equipment, 1965/6

* Shading coefficient decreases linearly from maximum value at normal incidence to constant lower value at all angles of incidence greater than 30 degrees.

*See fig: 42.