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PERFORMANCE STANDARDS FOR SPACE AND SITE PLANNING FOR RESIDENTIAL DEVELOPMENT

Light as a Characteristic of Space Control Standards

by

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FOREWORD

This report is one of a series concerned with space between buildings and related site development - a project that has been undertaken for DBR/NRC by the School of Architecture at the University of British Columbia.

The following reports have already been issued in the series: A Study of Performance Standards for Space and Site Planning for Residential Development (DBR Internal Report 273); four reports concerning space between buildings as a means of preventing the spread of fire (DBR Internal Reports 280, 281, 282, 283); Privacy as a Factor in Spacing Residential Buildings and Related Site Development (DBR Internal Report 336); and An Annotated Bibliography on Performance Standards for Space and Site Planning for Residential Development (NRC 6442).

The present study deals with performance standards for space and site planning for residential development. It was carried out by Dr. H. P. Oberlander, now Director of the School of Community and Regional Planning, and Professor W. Gerson, School of Architecture, University of British Columbia; and by Mr. A. Boyd, B. Arch., who served as Research Assistant.

One further report, which will deal with noise, remains to be published. When it is issued the series will provide a complete evaluation of all the conditions that must be considered in the planning of residential areas in Canada.

This research project was initiated with the enthusiastic participation of the late Professor Fred Laserre, then Director of the UBC School of Architecture, and has been carried forward with the full support of the present Director, Professor Henry Elder.

This information is being issued in the Divisional series of internal reports so that those responsible for the work can have the benefit of informed comments prior to publication in a more formal way. Comments will, therefore, be welcomed and should be addressed either to Dr. H. P. Oberlander, Director, School of Community and Regional Planning, School of Architecture, University of British Columbia, or to the writer in Ottawa.

Ottawa, Canada
July 1968

R. F. Legget,
Director, DBR/NRC

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PREFACE

This is part of the fourth study of an investigation of performance standards for space and site planning. The first study, an annotated bibliography, provides initial direction for all following work. It is now available from the Division of Building Research, National Research Council of Canada (NRC 6442). The second study investigates the main factors that determine the spacing of residential buildings and defines a range of community objectives that may be accomplished through rational space regulations, e.g., fire protection, daylight access, provision of air, mitigation of noise, protection of privacy, preservation of view, control of traffic and provision of usable outdoor space.

Following this program of research, the third study considers protection from the spread of fire by radiative heat transfer, and illustrates, among other points, the kind of open space that results from the application of rational performance standards for fire protection[2] to a typical single-family residential area and a typical urban housing group of multiple-family dwellings. It also demonstrates, in accordance with the second study, how the effects of the performance standard may vary with changes in roof height, wall height and length, window area, building setback and offsets (with respect to another building), ground elevation, the relative position of adjacent walls and with the use of various open and solid structural baffles.

It is the purpose of this, the fourth study, to investigate natural light measurement for site planning and the design and regulation of outdoor space. The study has two sections. The first is based on desk research consisting of analysis of significant literature. The second is a combined social and measurement survey applied in the field to a sample of apartments typical of three-floor walk-up developments. The scope of the whole study is limited to include daylight and exclude sunlight and orientation because of the separate complications such as comfort, view and aspect that might otherwise be involved.

This first section is material drawn mainly from physics and psychology references and from a group of zoning documents that illustrate different approaches to space regulation. Considerations made in the selection of material are that the information should represent the main features of the subject of daylighting, with particular emphasis on methods of daylight measurement and the daylight analysis of building spacing and site layout. A further consideration is that the content be useful for the field survey that concludes the study.

Many references were examined, particularly numerous special papers, articles and transactions of the lighting literature, but few were noted directly because it was possible to take advantage of several comprehensive and definitive works, especially Dr. John W. T. Walsh's recently published book, The Science of Daylight Design.

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If we are to improve the quality of future housing and the outdoor space it defines, we require the most rational form of design standards and regulations that can be obtained. Although standards for siting and open space are not the only considerations in determining the adequacy or form of our housing, they nevertheless have a large impact on the freedom designers may exercise and the over-all efficiency that may be achieved in covering the urban land resource. The rational sizing and allocation of outdoor space bears directly on the over-all standard of livability that may be achieved, particularly in the dense urban residential setting.

For the developer, space and siting standards represent an unwelcome intrusion in his real or imagined right to develop private property. If the intrusion is thought to be unreasonably restrictive it may be because his profit expectation is limited in the "public interest." In fairness, however, he has also had cause for complaint in arbitrary, ill-defined requirements that serve little purpose other than the simplification of civic administration. On the other hand, unreasonableness in designers may be found in the limitation of creative initiative. Again, in fairness, it can be found in requirements that have the effect of eliminating any real opportunity for good design, particularly where high demands for housing cause rigidly set bulk envelopes to be filled to capacity.

Serious efforts for the improvement of our residential site planning standards must include programs to achieve more sensitive controls that are both rational in content and flexible in form. It is the contention of the authors that such controls can be formulated if they are based on a performance principle rather than on rules-of-thumb or practice that is maintained only because of tradition or the way it serves the exigencies of bylaw administration.

According to the performance principle, outdoor space ought to be defined or specified, first, by the functions it performs, and second, in relation to the size and dimension of land and buildings in a given situation. A third specification, open space controls, ought in principle to serve the residential interests of the urbanite as a property user in a broad sense rather than as a property owner or developer on the one hand and as a tenant on the other.

Clarification of the objectives of site planning regulations is fundamental in obtaining rational residential open space controls. Although public health, safety, convenience, welfare, prevention of overcrowding, the preservation of amenity and the like are commonly accepted as broad community objectives of site planning regulations, the specific objectives that have been identified are those that are most pressing and afford easy methods of measurement and administration. These are and have been primarily matters of safety involving fire protection, health, light and air. Other factors such as noise, privacy, view, traffic and usable open space are also considered suitable for regulation, primarily because of the movement of the communities' interest in housing away from complete preoccupation with security to matters of livability. Today the most unhealthy and dangerous residential conditions of the last century have been largely overcome.

There are two primary problems in obtaining functional and rational site planning controls. First, the environmental conditions in question - daylighting, spread of fire, transmission of noise, ventilation - must be physically measured in terms of the open space defined by buildings. This is necessary so that the effect, with respect to the environmental conditions, can be known of changes in the open space brought about by changes in the buildings forming it. Perhaps the best examples of such measurement are the space regulations of the National Building Code of Canada for the spread of fire by radiative heat transfer and the British Waldram analysis of space to determine the level of daylighting indoors, which is the subject of this study.

The second problem is primarily a matter of valuing. Having established a useful basis of measurement for the environmental conditions in question, it is vital that a method be available for determining the importance people give, for example, to different levels or conditions of daylighting. Of course, to have meaning, the methods of physical measurement must be related to those of the social measurement used to determine the values. At present, in this country, there is no known example of such valuing, although the British, Dutch and Scandinavians have developed a number of continuing projects in social measurement related to site planning controls. In Canada the municipalities and cities responsible for site planning controls follow no discernible pattern in their valuing, except perhaps tradition.

PART ONE: LIGHT, DAYLIGHT AND SEEING

LIGHT ENERGY

Matter is luminous when it emits light because of high temperature, electrical excitation, or certain chemical or physical processes (Ref. 1). All materials at temperatures above absolute zero are believed to emit and absorb radiation continually (Ref. 2). According to the quantum theory radiation exists in the form of certain discrete portions, or quanta, of energy and the energy of each separate quantum is inversely proportional to its wavelength (Ref. 3). For some radiations of shorter wavelength (Figure 1) the quanta take on immense importance for they are capable of stimulating the human retina so that it may perceive "light."

> "Careful experiments show that if two adjacent rod cells on the retina each receive a quantum within 1/70 second, the eye will just perceive a flash of light. To achieve this sensitivity the light must be at the wavelength of maximum sensitivity (510 millimicrons, in the blue-green, for a dark-adapted eye) and must be received by rods in a region subtending less than 10 ft. of arc, located 20 deg. off the centre of the retina where dark vision is most acute (Ref. 4)."

The reception of a large number of quanta gives the impression of continuous reception and produces a continuous visual stimulus.

TEMPERATURE AND LIGHT

If the temperature of a specially constructed object known variously as an ideal radiator, perfect radiator (Ref. 5), black-body, Planckian body, and full radiator (Ref. 6) is raised, the total radiation emitted increases rapidly, the emissive power being equal to the fourth power of the radiator's absolute temperature (Ref. 7). For a particular absolute temperature, radiation of all wavelengths is emitted; the spectrum is continuous. But for different temperatures of the body the relative abundance of radiation of different wavelengths in the spectrum changes. The maxima of radiation is distributed at shorter and shorter wavelengths (see Figure 1) as the temperature increases, so that when first seen the black-body or full radiator appears red, then white, and finally blue at the highest temperatures (Ref. 8) (Figure 2).

COLOUR TEMPERATURE OF SUNLIGHT

The colour of a light is described by comparing its spectral distribution (which may not be entirely defined by temperature) to a similar distribution determined for a black-body or full radiator (see Figure 2) at a particular absolute temperature (the temperature entirely defines the radiator's distribution) (Ref. 9). Measurements of the total illumination of sun and sky, with cloud cover of one-eighth or less, at Wellington, New Zealand, established a spectral distribution (Figure 3) approximating that of a black-body radiation of 5740°K, (Ref. 10). Similar measurement of illumination from the sky alone approximates a black-body radiation of 11,500°K on clear days and 6,200°K on densely overcast days (Ref. 11). The spectral distribution of the sun alone may commonly approximate a black-body radiation of 5,400°K (Ref. 12).

VARIETY OF SKYLIGHT COLOUR

In the course of general observation the light of the sun and sky or that of a densely overcast sky is often described as white or whitish, and this may be so if most of the energy of the spectral distribution is concentrated at wavelengths corresponding to a "whitish" color sensation. More particularly, the colour (and spectral distribution) of the different natural or sky and sunlights does vary to a considerable extent (Ref. 13), because visible solar radiation, seen or measured at the earth's surface, is modified by the extent and quality of the atmosphere and the angle of elevation of the sun (Ref. 14). For this reason the true colour of objects may appear to change with different weather, with different times of the day (Ref. 15), and at different places on the earth's surface.

LIGHT DETECTORS

There are many detectors of electro-magnetic energy, but the eye is the most important detector of visible energy. Other light detectors are the common camera and the photoelectric light meter. In the study of daylight only the eye and the photoelectric meter have immediate importance and some idea has already been given of the very sensitive nature of the eye.

THRESHOLDS AND CONTRAST SENSITIVITIES

The eye has two basic sensitivities, (Ref. 16) one of the threshold of light intensity, usually called the absolute limen after the Weber and Fechner Law, (Ref. 17) and the other of contrast sensitivity or ability to perceive differences in brightness. Both sensitivities depend on whether vision takes place at very low levels of illumination (scotopic vision - usually experienced at twilight, but not uncommon in some dwellings during daylight hours) or at higher or daylight levels (see Figure 4).

SCOTOPIC VISION

At very low levels of illumination the eye is said to be "dark adapted", (Ref. 18) and vision (which here depends on rod cells in the retina) is colourless, consisting of a series of greys with black and white as terminal intensities. The absolute sensitivity of the eye, however, is comparatively high, (Ref. 19) although shape sensitivity or visual acuity (the ability to detect detail) is low (Ref. 20).

PHOTOPIC VISION

At higher levels of illumination the eye is said to be "light adapted," (Ref. 21) and vision (photopic vision, which here depends on cone cells in the retina) includes colour perception, with violet and red as terminal wavelengths of visible energy. The absolute sensitivity of the "light adapted" eye is comparatively low, (Ref. 22) while acuity is comparatively high (Ref. 23).

CONTRAST SENSITIVITY AND BRIGHTNESS

Contrast sensitivity or the ability to perceive differences in brightness corresponds in the most basic way to the ability to perceive objects or to distinguish one from another. Tests performed since 1760 (Ref. 24) have attempted to illustrate the relation between just-noticeable difference in brightness ("jnd" after Fechner's work) and the brightness of the field of vision. It has been found, in general, that as it gets lighter (adaptation brightness rises) contrast sensitivity increases, but between brightnesses of about 20 and 2000 millilamberts (about 6 and 600 candles per ft^2) contrast sensitivity is constant; here the effort of seeing is at a minimum (see Figure 5) (Ref. 25).

With a net reflection factor of 0.5 (a figure that could easily be lower for many residential conditions) this range is comparable to an illumination of 37 to 3700 ft candles, (Ref. 26) which is easily attained in daylight outdoors (where illumination is seldom less than 300 ft candles), but only rarely indoors even with artificial lighting. Figure 6 provides a graphic outline summary of the above discussion.

PERIPHERAL AND CENTRAL BRIGHTNESS

Brightness of the field of vision usually involves central and peripheral brightnesses, and it appears to be established (Ref. 27) that when the two are the same strain on the eye is at a minimum. It is a matter of common experience that glare may totally eliminate effective vision.

SENSITIVITY OF LIGHT METERS

The sensitivity of the photoelectric meter compares very roughly to that of the eye (see Figure 7) (Ref. 28). For the practical study of daylight and the illumination of rooms it renders adequate results if properly equipped with an integrating head (usually hemispherical) to eliminate the so-called "obliquity" or cosine error (Ref. 29). Other light meters such as the Bunsen grease-spot photometer, the Lummer-Broadhun photometer, and the flicker photometer compare light intensity with the direct use of the eye, but seem best suited to the laboratory (Ref. 30).

UNITS OF LIGHT

Only that part of the radiant energy that affects the eye (see Figure 1) is of importance. If a light source (the sun, an overcast sky, a full radiator) emits visible energy at a particular rate of flow the unit in terms of which the rate of flow or flux of visible radiation is measured is the lumen (Ref. 31).

LUMINANCE AND ILLUMINATION

In natural light calculations luminance (of the sky) is based on the conception of a uniform diffuser or surface having the same luminance in all directions:

> "The unit adopted is the luminance of such a surface when the total flux it emits is one lumen per unit area. When the emission is one lumen per sq ft the luminance is one foot-lambert (Ref. 32)."

And:

> "The convenience of the foot-lambert as a unit in which to express values of sky luminance arises from the fact that the illumination, in lumens per sq ft of a horizontal surface exposed to a complete hemisphere of sky of uniform luminance, is equal numerically to that luminance in foot-lamberts. Thus, for example, a uniform sky of luminance 500 foot-lamberts gives an outdoor illumination of 500 lumens per sq ft (Ref. 33)."

LUMINOSITY

The term "brightness" is usually reserved for reference to the sensation aroused when a luminous surface is viewed, "luminous" denoting a physical attribute of the surface. The term "luminosity" is normally found in place of brightness (Ref. 34).

SKY AS A LUMINOUS SOURCE

The level of natural illumination at a point on the earth's surface varies with the position of the point, with the thickness of terrestrial atmosphere traversed by radiant energy reaching the point, with the fraction and part of the sky unobstructed to the point, and finally, with time and weather conditions.

EFFECT OF ATMOSPHERE

Some of the sunlight travelling through the earth's atmosphere is absorbed, the amount depending on the thickness and density of the atmosphere traversed (Ref. 35). Measurements have determined that the transmission factor for vertically incident light is 0.80 and that light incident at any other angle will have a smaller transmission factor. For example, light incident at 45 deg has a transmission factor of 0.73 (Ref. 36). The factor by which transmission is decreased relative to that when light is vertically incident is termed the "optical air mass" and is equal to sec z where z is the angle of incidence (Ref. 37).

EFFECT OF CHANGING WEATHER

Apart from the effect of the earth's daily and seasonal movement, changing weather brings about the greatest variety of natural lighting conditions:

> "To give some idea of (the range of values of daylight illumination observed for any particular time) it may be said that on nineteen occasions out of twenty the difference between the observed value and the mean value does not exceed about 25 per cent in summer and 50 per cent in winter. Under exceptional conditions, however, much wider variations may occur. For instance at mid-day in August (at a point in England) the illumination from a heavily overcast sky may be as low as 700 lumens per sq ft, while on a bright day with a thin cloud layer and hazy atmosphere it may reach nearly 5000 lumens per sq ft; the average value is 3000 lumens per sq ft. On a dull November day a noon illumination of as low as 280 lumens per sq ft has been observed, while in late October on a day with white clouds on a blue sky, the value has exceeded 2,300 lumens per sq ft.
>
> "The sky conditions that result in low values are those usually described as "heavily overcast," "dull" or "grey," "thundery" and the like. High values are observed on clear days with white clouds in a blue sky. In particular, white cumulus clouds with the sun shining on them give very high values and a thin haze covering the sky and illuminated by the sun gives much higher than those found when the sky is perfectly clear (i.e. the illumination due to sunlight alone for a surface normal to the sun's rays is approximately 10,500 lumens per sq ft) (Ref. 38).
>
> "The steadiest conditions are found on dull days when the sky is overcast and there are no storms. The most variable days are those with white clouds scudding across the sky. In particular, sunlit cumulus clouds with the sun shining on them produce large variations of illumination as they change position in the sky (Ref. 39)."

OVERCAST SKY

The overcast sky (with no storms) is of greatest interest for daylight calculations because it represents a frequent steady minimum condition (Ref. 40). In early daylight design work the luminance distribution of the overcast sky was considered to be even, (Ref. 41) but in 1955 the International Commission on Illumination officially adopted a luminance distribution mathematically defined by a formula developed by Moon and Spencer (Ref. 42). Figure 8 shows the typical luminance distribution in a densely covered sky for a solar altitude of 40 deg. It may be seen that the chief characteristic of this distribution is that the luminance at the horizon is about one-third that at the zenith (Ref. 43).

HOURLY AND SEASONAL ILLUMINATION CHANGES

The relation between time (of day and year) and the level of natural illumination is really the relation between the daily and yearly movements of the earth and natural illumination. Figures 9, 10, 11 and 12 show how the illumination from the cardinal octants of the sky varies according to time throughout the day and for each month of the year. As these figures are derived from data recorded in Great Britain (Ref. 44) they represent particular cases. For purposes of illustration, however, the general shape, distribution and order of these curves might be expected to exist for other marine climates within Great Britain's range of latitude.

THE SUN'S ELEVATION AND ILLUMINATION

A relation exists between the angle of elevation of the sun and the average level of natural illumination. This relation (see Figure 13) may be expressed with a fair degree of accuracy by the product of 52 and the sun's altitude in degrees (Ref. 45), but this expression is useful only for the north and south octants (see Figure 11) (Ref. 46).

SOLAR RADIATION AND ILLUMINATION

It might also be expected that a relation exists between total solar radiation and natural illumination. Following tests in different parts of the world, including quite extensive ones in South Africa, the United States, Great Britain and Australia, (Ref. 47) the ratio of natural illumination in lumens per sq ft to solar radiation in calories per sq cm per min has been found to range between about 6000 and 6600, although the ratio may be rounded off to 7000 (Ref. 48).

In Canada radiation is recorded at a number of stations across the country, and both illumination and radiation are regularly recorded at Scarborough, Ontario, by the Meteorological Branch, Department of Transport (Ref. 49). These records (Scarborough) indicate a ratio (illumination to radiation) of 6815 (Ref. 50).

LATITUDE AND ILLUMINATION

Finally, a relation between latitude and natural illumination may be expected (though never demonstrated to any substantial extent) (Ref. 51) if it is considered that the effect of a change in latitude corresponds to a change in the angle of elevation of the sun. Figure 13 indicates that a degree rise in latitude will be accompanied by a decrease in natural illumination of about 50 to 60 lumens per sq ft.

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PART TWO: THE MEASUREMENT OF NATURAL LIGHT

TWO APPROACHES TO DAYLIGHT MEASUREMENT

Daylight conditions at a point are assessed either by measuring the quantity of light in illumination units (lumens per sq ft) or by determining the ratio between the illumination at the point and the illumination that would exist at the point if no obstructions were present. Interest in the former or "quantity" approach has centered in the U.S.A., while the latter approach has been developed and used extensively in Europe (Ref. 1).

COMPARISON OF APPROACHES AND THE QUANTITY METHOD

The relative importance of the quantity and ratio approaches depends on a number of factors quite apart from the possibility that each is neither more nor less than uniquely useful. It would appear in the general sense in which comparison of conditions is made necessary by standards together with the degree to which our assessment of lighting conditions depends on comparative brightness, (Ref. 2) that the ratio method is simply more useful and more "realistic." On the other hand, the quantity method will have special importance where design considerations place particular emphasis on fenestration:

> "This prediction technique is a lumen method of daylighting design. It is based on the total incident illumination on the fenestration area. Since the illumination from below the horizon is indirect lighting within the room, and the illumination from above the horizon is mostly direct lighting, it is necessary to predict the illumination distribution within the room from each type of source separately. The illumination from direct sun incident on the fenestration area is distributed differently from that of sky light with no sun on the fenestration area. Since direct sunlight within the room is not usually desirable, some type of sun control is necessary to eliminate it.
>
> "The daylight distribution within a room from a particular exterior condition is predicted for three locations within the room. These three locations are on a centreline perpendicular to the wall of the fenestration under study. The maximum point is located five feet in from the fenestration wall, the minimum point five feet in from the wall opposite the fenestration area, and the mid-point is in the centre of the room. The illumination is predicted at a work plane height of 30 inches.

"The illumination from the sky (or sun and sky if the sun is incident on the fenestration area) is predicted, and then the illumination from the ground. All of the values of the illumination from each source are then added to obtain the total daylight illumination at any one prediction point. In the case of multilateral daylighting the illumination is predicted for each fenestration area separately. It should be noted that in multilateral daylight predictions the maximum point for one fenestration area may be the minimum point for another fenestration area.

"After a particular exterior condition has been established, the actual prediction of the daylight distribution within the room is quite simple. The daylight at any one of three prediction points can be computed from the equation:

$$E = E_i \times A_f \times C.U. \times K$$

where

E = work plane illumination at the particular point,

E_i = illumination incident on the window from a particular source (sky, sun and sky or ground),

A_f = light transmitting area of the fenestration,

C.U. = coefficient of utilization for a particular fenestration (and/or fenestration and control),

K = numerical multiplying factor

"It is not economically feasible to develop a daylight prediction technique that would cover all possible daylighting designs. However, this daylight prediction technique has been expanded to cover most practical daylighting designs. It has been amplified to cover daylighting controls such as overhangs, venetian blinds, and diffusing controls.

"The technique was originally designed to cover rooms varying from 10 feet to 40 feet in length and width, with ceiling heights from 8 to 14 feet. Recently the technique has been applied to rooms 80 feet long and 40 feet wide with satisfactory results.

"The simplicity and ease of the prediction technique can only be appreciated by studying various examples of its application. The complete technique with examples and all the necessary tables to determine the exterior lighting conditions will be available in a brochure from the Libbey-Owens-Ford Glass Company. Excerpts from this prediction technique are available in various papers presented before the Illuminating Engineering Society from 1953 to 1957 (Ref. 3)."

RATIO METHOD

In the ratio approach the unit of measure is the daylight factor expressed in percentages and officially defined as follows (Ref. 4).

"The daylight factor is a measure of daylight illumination at a point on a given plane, expressed as a ratio of the illumination on the given plane at that point and the simultaneous exterior illumination on a horizontal plane from the whole of an unobstructed sky of assumed or known luminance distribution. Direct sunlight is excluded from both interior and exterior values of illumination."

COMPONENTS OF DAYLIGHT FACTOR

The natural illumination at the point on the given plane indoors in this definition may be the sum of:

1. light penetrating to the point directly from the sky (Sky Component);
2. light reflected to the point from exterior surfaces (External Reflected Component);
3. light reflected to the point from interior surfaces (Internal Reflected Component).

It follows from the definition that the daylight factor at the point on the given plane is the sum of the above components (Ref. 5).

SKY DISTRIBUTION COMMONLY USED

The sky of assumed or known luminance distribution mentioned in the definition is most commonly a densely overcast sky, accepted by the International Commission on Illumination since 1955 as a standard sky for daylighting calculation and measurement (Ref. 6).

RELATIVE SIZE OF EACH COMPONENT

Determining the relative size of the three illuminating components (SC, ERC, and IRC) is really a matter of case-by-case calculation, for it is common experience that great variety is to be expected in the size and arrangement of windows, of external surfaces or obstructions, and in the amount of sky clearly visible. Moreover, the reflective quality of surfaces and the design of window coverings (blinds, curtains, etc.) varies considerably. It does seem possible, however, to rely on several instructive generalities:

(1) "The glazing material in the window (whether it is glass, clear, translucent, figured, etc) may limit the transmission of light normal to the window by about 10 per cent. The transmission factor of light incident at 60 deg is about 83 per cent (see Figure 14). There is necessarily no way of knowing to what degree light transmission is affected by window coverings without detailed examination. However, the effect of dirt on glass may create transmission losses of 20 per cent, though 30 to 50 per cent may be expected in industrial areas (Ref. 8).

(2) "The light reflected to a point indoors from an external surface or obstruction compared with the light reflected from an equal area of sky is negligible so long as the sky component is appreciable (0.5 per cent or more). However, as less sky becomes visible the external reflected component grows until, together with the internal reflected component, it provides all the illumination (Ref. 9). It has been found, on the average, that the brightness of an obstruction is one-fifth that of the sky it obscures (Ref. 10) but if the obstructing surface is far enough away so that a slight intervening haze exists then the luminance of the haze may have all the importance (Ref. 11).

(3) "The internal reflected component may be the largest single component if no sky is visible at the point considered. This component depends on relative room dimensions, window size, and surface reflection factors, and, very approximately, it may be taken as constant for all points on the same plane though constancy evidently improves as reflection factors are increased and the ceiling height is raised (Ref. 12). A selection of reflection factors for both dirty and clean surfaces is contained in Table I.

(4) "The design, arrangement, proportion, location etc., of the window opening determines substantially the kind or quality of natural illumination in a room. The important considerations appear to be whether the plane of the window is vertical, tilted, or horizontal (skylight), and if vertical, whether the window head is high or low and what general shape the window takes. Very briefly, the illumination from a horizontal window is very much greater than that from a similar vertical window and by increasing the height of the window head substantial increases in illumination may be secured, especially in the interior areas of rooms quite apart from the benefit of securing light at a higher angle of incidence (Ref. 13). A more detailed account of the performance of various window designs is contained in Reference 2."

In summary it is sufficient to say that where an "international" overcast sky is visible to any substantial extent the sky component dominates in determining the daylight factor. And where the sky is not visible the daylight factor is due entirely to the external and internal reflected components. But to the extent that the internal reflected component is the same for all points in a given room and to the extent that most rooms represent about the same net reflectance condition, the internal reflected component might be considered a constant (Ref. 14) where the general daylighting quality of many similar rooms is being compared.

TABLE I

REFLECTION FACTORS FOR SOME SURFACES AND MATERIALS

	OBJECT	REFLECTION FACTOR* (PER CENT)
1.	Concrete	45 (15% for dirty surface)
2.	Portland Stone	60 (20% " " ")
3.	Dark Stone	30 (10% " " ")
4.	Yellow brick	35 (12% " " ")
5.	Red brick	25 (8% " " ")
6.	Foliage	20-30
7.	Open ground	5-10
8.	Snow	70
9.	White on plain plaster ceiling	80
10.	Brown carpet floor	10
11.	Dark plywood floor	20
12.	Pink plaster wall	65

*The reflection factors have been selected from two sources:

1. Walsh, J.W.T., The Science of Daylight Design, London, Pitman, 1961, p. 86, Table 9. - (Items 1 to 8 above).

2. Hopkinson, R.G., J. Longmore and A. Graham, Simplified Daylight Tables, H.M.S.O., London, 1958, p. 23, 24 - (Items 9 to 12, above).

METHODS FOR DETERMINING THE DAYLIGHT FACTOR

The daylight factor (for stable overcast conditions) can be measured by taking photo-electric meter readings inside and outside simultaneously, (Ref. 15) or, with some loss of accuracy, inside and outside at intervals. It is also possible to measure the daylight factor directly with several different photometers and photo-electric arrangements, (Ref. 16) or graphically by a special photographic device, (Ref. 17) or it can be calculated using specially constructed sky diagrams or co-ordinate grid networks, (Ref. 18) or with tables (Ref. 19) and mathematical formulae (Ref. 20). There are, in fact, many methods for determining the daylight factor and they may be described as direct instrument methods, as mathematical calculation methods, or as graphical methods.

THE DIRECT INSTRUMENT METHOD

The problems encountered in the use of direct instrument methods appear to be mainly procedural, (Ref. 21) involving such difficulties as finding an unobstructed position for the measurement of the illumination from the whole sky. The problems arising from the instruments themselves can evidently be satisfactorily provided for (Ref. 22). The main feature of the direct instrument methods is that they record "real" conditions, while the calculation and graphical methods necessarily involve highly reliable assumptions concerning the distribution of sky luminance (Ref. 23).

THE MATHEMATICAL CALCULATION METHOD AND TABLES

Although it is possible to calculate daylight factors by mathematical formulae (Ref. 24) the whole procedure is lengthy and complex compared to the use of a sky component table specially prepared for the height and width of vertical windows and the distances from the windows to the points where the daylight factors are to be measured. The best example of such a table is that produced by R.G. Hopkinson, J. Longmore and A. Murray Graham for the Department of Scientific and Industrial Research in Great Britain (Ref. 25). In addition to sky components, this study provides for internal and external reflected component approximations.

THE GRAPHICAL METHOD AND THE WALDRAM DIAGRAM

The main, and probably most direct, graphical method used for determining sky components, and to a fair approximation the external reflected components, is the Waldram diagram with ordinates based on the CIE sky luminance distribution (Ref. 26):

> "When it is desired to ascertain the sky (component) at a point (generally alluded to as the reference point) on the table plane of an obstructed room, measurements are made, usually from drawings, of the angles of elevation and bearing subtended at the reference point by the salient points of the windows and of what is visible through them, whether sky or obstruction. These salient points are then plotted on a flat projection of angular co-ordinates, or lines of celestial latitude and longitude, and joined up to form a picture of the window and its aspect as viewed from the reference point.
>
> "The measured area of the plotted patch or patches of sky on that picture, divided by the area of the circular flat projection of the complete hemisphere of sky above the horizon, or by twice the area of the semi-circular flat projection of the quarter sphere of sky visible from a window in a vertical wall, is the sky (component) at the reference point. The scale of the projection is immaterial (Ref. 27)."

An explanation of the main features of the Waldram diagram is contained in References 18 and 26, but Reference 18 does not indicate that the problem of measuring the area on the diagram is much reduced by the use of a planimeter.

OTHER GRAPHICAL METHODS

In addition to the Waldram diagram there are many special graphical devices for determining daylight factors (Ref. 28). A number of these have been created to simplify particular aspects of commonly occurring problems, while others seem to reflect the designer's "way of working." The International Commission on Illumination is at present preparing a design manual for the purpose of presenting and comparing a number of the design systems now available (Ref. 29).

PERMISSIBLE HEIGHT INDICATORS FOR EXTERIOR USE

Of the special graphical methods derived from the Waldram diagram, the most important for application outside buildings is the so-called permissible height indicator for determining whether a particular site layout conforms to a specific daylight standard. The idea of the indicator is based on the fact that the shape of a patch of sky created by the outline of buildings can change without necessarily changing the sky factor derived from it. Different equivalent shapes of sky can be expressed by the indicator with pairs of horizontal and vertical angles. The indicators are designed for testing, either from points midway between buildings or from points on buildings to other buildings. Actually the indicators for testing from points midway between buildings are developed for use with lot lines and street centre-lines, but in theory this fact need not be considered. The importance of the indicator is the ease and speed with which it can be applied in determining and specifying physical values of daylighting. It provides for a very close but flexible control of the skyline. In Britain the indicator is commonly employed in both design and control work and is recommended there by the Ministry of Housing (Ref. 30). An illustration of the application of the indicators is shown in Figure 15.

A REGIONAL STANDARD SKY ILLUMINATION VALUE

The use of tables and diagrams involving standard sky luminance distribution, especially that of the overcast sky, raises the question of what numerical value to apply to the illumination from the whole sky because this value varies throughout the day and year (see Figures 9, 10, 11, 12):

> "The approach to this problem taken in Britain and a number of other countries has been to base the (value) on tolerable minimum conditions. The effect of sunlight is therefore ignored and a completely overcast sky is assumed as the light source. The tolerable minimum generally accepted is that level of natural illumination that is exceeded for 90 per cent of the daylight working hours (Ref. 31)."

Values determined in this way may range from 500 lumens per sq ft (Teddington, England) to 1000 lumens per sq ft (Pretoria, S. Africa) (Ref. 32). Appendix A illustrates the procedure followed in determining the daylight illumination value for the whole sky for Ottawa, Ontario.

USE OF MEASUREMENT METHODS IN DEVELOPMENT CONTROLS

The commonly used techniques for controlling daylighting are mainly pragmatic attempts to express the basic geometry of daylight transmission within the context of the architecture of the street. Their origin evidently lies in the early tenement house laws that very sensibly expressed open space requirements as a function of building height and street width (Ref. 33).

When applied to parallel rows of attached or close buildings of equal height the common code techniques are able to provide close control of outdoor space for daylighting standards because the problem has only one variable. The principal difficulty is with free-standing buildings that require daylight access on all sides. This is particularly true if groups of buildings of differing height are to be sited on one large area without definite relationships to streets or property lines. Here the traditional control techniques are clearly inadequate and must be replaced by more direct devices such as permissible height indicators.

It is quite plain from the science of daylighting that the regulation requiring window areas as a ratio of floor areas is a rule-of-thumb that can guarantee only a nominal effect (Ref. 34). The commonly used by-law techniques are the following:

1. Yards and setbacks.

   Yards and setback requirements are commonly expressed simply as linear values but may be expressed angularly (see Figure 16) or in detailed and graduated form (see Figures 17 and 18).

2. Height limitations.

   In combination with yard, setback and court requirements, height limitations describe an envelope of space within which a building may be built.

3. Vertical and average vertical light angles.

   Yard and height limitations are expressed equally well and with some increased flexibility in application by vertical angles measured either from lot lines or road centrelines to the building cornice. The vertical angle is a more direct, effective and flexible expression of how natural light actually reaches dwellings than are height and yard expressions. This is particularly true if the angle is expressed as an average requirement and if narrow building sections or sections of width less than a given amount are exempted from control (see Figure 19).

4. Horizontal areas or angles of daylight access.

This device is normally specified as one or two horizontal arcs of given radius that must be obtained within an over-all horizontal limiting arc or light acceptance angle measured at the window or, to avoid the legally advantageous positioning of windows, at the centre of a room's exterior wall (see Figure 20). This device is not fully effective unless the radius is sufficiently large or an appropriate vertical angle is also specified.

SUMMARY

It is now established that the level of natural lighting indoors depends on:

1. the luminance of the sky, which may be easily and accurately measured and, for design purposes, predicted with reasonable accuracy for any local or regional area having the necessary meteorological records (see Appendix A);

2. the nature of the daylight transmission path, which depends on where the path originates in the sky and/or on surrounding reflecting surfaces (but mainly in the sky), its shape, size, and direction which results from the skyline and the geometry set-up between it, the sky, and the window, and finally, on the window's size, shape, glazing, and position with respect to an indoor location.

It is also established that to provide for daylighting standards indoors the space between buildings must first be effectively determined so that the shape, size, glazing and location of windows can be properly worked out. To do this several well-tested and uncomplicated methods for working from either the outside or inside are now available:

1. Working from the outside, so-called permissible height indicators (see Figure 15) can be constructed and applied to any site plan to test daylight conditions (Ref. 30).

2. Working from the inside, the fraction of the outdoor light that reaches an interior point can be assessed with either daylight tables or diagrams such as the Waldram diagram (Ref. 14).

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PART THREE: THE VALUING OF DAYLIGHT

THE NEED FOR A SATISFACTORY DAYLIGHTING STANDARD

The problem that remains is to determine a satisfactory daylighting standard. The physical science of daylight is substantially complete, but it offers no method of assessing the importance of particular levels or conditions of daylighting. Now the need is to find the inherent qualities of daylight, as distinct from those of any other kind of light, that can furnish unique criteria with which to value it and help provide credible information about the meaning of daylight quantities and conditions that are tolerably minimum, sufficient or adequate, optimum, acceptable, desirable, etc.

APPROACHES TO DAYLIGHT VALUING

Because the consequences of natural light are both functional and psychological, it is doubtful whether there can be a single approach to the problem of its valuing. The form of a carefully determined residential daylighting standard must, presumably, be a matter of compromise between the amount and quality of light needed for satisfactory seeing and the conditions of exposure or access to daylight needed to satisfy what can best be termed a visual oecological balance between indoor and outdoor space.

The need for a satisfactory residential daylighting standard has existed because the provision for some community and individual interests, particularly those satisfied by denser forms of development, naturally conflicts with the provision for the interest in daylight. As a result, whatever has been accomplished for the valuing of daylight is essentially for the purpose of its control and protection. There are four distinct areas where valuing has occurred:

1. The legal protection of daylight as a natural right of the individual property owner (in Britain): The valuing of natural light is necessary so that infractions and damages can be determined in particular cases.

2. Contemporary zoning and development controls: The daylighting objective of these codes or by-

laws is commonly to secure, broadly and indirectly, and with generalized measures, a nominally valued community interest in daylight.

3. Functional needs of seeing: The importance of different values of light has been determined in accordance with the function of the eye and the performance of various seeing tasks under various lighting conditions.

4. The importance of existing values: It has been possible to rate existing daylighting conditions with the help of social survey techniques. The occupant's judgements of the acceptability and desirability of different lighting values are obtained by questioning a large number of people living in selected forms of development.

NOMINAL PROVISION: THE EVIDENT DESIRE FOR DAYLIGHT

As the development of the so-called artificial climate proceeds, people appear less concerned with the prospect of spending half or even the whole of working days without any natural light. But it seems inconceivable that all but a minute number would not desire some direct penetration of, or access to, daylight in their homes. In approaching the problem of value this much seems certain, but the questions remain of "how much" and "under what conditions."

THE VALUE OF DAYLIGHT EXPRESSED AS A NATURAL RIGHT

The first material valuing of natural light occurs with the legal protection of daylight, which was accomplished in Roman times, and is still in Britain, within the framework of the concept of natural rights (Ref. 1). Roman jurists recognized in their law of property that certain things were by their nature res extra commercium and could only be used but not owned or individually controlled (Ref. 2). The relation of an individual to the natural media of light and air, in the sense that life depends upon them, could not be interfered with. As far as natural light is concerned history shows that this understanding has remained, especially in Britain where the early Roman precepts were incorporated and first appeared as the Law of Ancient Lights in the reign of

Richard Coeur de Lion in 1189 and later in 1832 as Lord Tenterden's Act or the Prescription Act, which is still effective (Ref. 3).

The main point of this development is that interference with a natural right to use a communal resource is made legally offensive. In this way the interest in daylight was and is secured on an individual basis and in a direct and specific way by defining compensation due for light lost in a given case. In Britain a value for daylight roughly equal to one foot candle of illumination from an overcast sky of illumination equal to 500 foot candles came to be accepted as a standard of inadequacy for determining an offense and damages (Ref. 4).

THE VALUE OF DAYLIGHT EXPRESSED AS COMPENSATION FOR THE LOSS OF LIGHT

Roman records show penalties for interfering with light that amount, for example, to three years' pay of a common soldier. British jurists have upheld injunctions to restrain or pull down offending structures and have awarded money compensation as high as 15,000 pounds in 1939 (Ref. 5).

THE EFFECT OF THE UNIQUE TRADITION OF NORTH AMERICAN LAND PROPERTY LAW ON THE PROTECTION OF DAYLIGHT

In North America the historical connection of natural rights was not made in the same way. The successive impacts on the form of the law of the philosophies of free will, liberty and free self-assertion seem to have had more effect even up to the present than anything else (Ref. 6). First, the law came to exist to maintain a natural equality conceived as an ideal equality in opportunity to do things; it easily passed into a conception of free individual self-assertion where men mainly required of it that it allow them, without molestation, to make what they could of continually unfolding opportunities. Land was (and still is) acquired often for its own sake and traded like any commodity; the law secured it, including the extensive private control of its development, and what George Ford, a New York building code authority, wrote in 1931 is still true:

> "The Law of Ancient Lights is based entirely on the theory that any man can control his neighbour. It means that if a man has happened to have a particularly low building on his land for at least 20 years, any one of his neighbours can prevent him from ever erecting any higher building; or, if he does erect a two-storey building instead of the former one-storey building, his neighbours can all hold him up for damages. However justified this may be under British law, it is inconceivable that this principle could stand the test of the American courts (Ref. 7)."

Not only is this still true but the reverse of the British principle obtains:

> "To prevent the obstruction of daylight for over 20 years, on the south side of the Harriman Building, 39, Broadway, New York, the sum of 742,500 dollars was paid in 1929 (Ref. 8)."

In Canada most provinces have specifically rescinded the right of light (Ref 9).

THE VALUE OF DAYLIGHT IN CONTEMPORARY ZONING AND DEVELOPMENT CONTROLS

Where daylighting interests have been secured in the past the law controlling the development of land property has secured them individually and mainly on behalf of the owners of property. Today this law is evolving from that of an institution of private law, implying extensive individual control of land development, into an institution of public law in which development is controlled increasingly through incidental legal institutions such as the building and zoning by-laws. These by-laws have been created to secure, collectively and more and more for the users of property, individual standards in terms of social standards not only of safety but livability (Ref. 10).

More specifically, the British Town and Country Planning Act of 1932 created the first communal rights of light by requiring all new buildings to leave adequate light and air to all neighbours. In Canada the Provincial Planning and Municipal Acts have empowered local governments to enact zoning by-laws that may regulate, as in section 9 (1) of British Columbia's Town Planning Act, a number of development features having a direct but unqualified bearing on residential daylighting:

1. the height, ground area and bulk of buildings;

2. the building lines, fence lines and areas of courts, yards and other open spaces.

These acts give no hint as to specifically what daylight value is desired. Nor do they specify or even suggest methods or procedures for valuing beyond the general use of open land areas and open space. The whole question is given to the local governments to settle. The Acts only direct them to give "due," not specific, regard to a number of community interests that are regularly listed. Again, for example, in section 9 (1) of the British Columbia Town Planning Act the local governments are to provide valuing for the following considerations: (the first three seem directly related to natural light)

1. promotion of public health, safety, convenience and welfare;

2. prevention of overcrowding of land and the preservation of the amenity of residential district;

3. securing of adequate light, air and reasonable access;

4. value of land and the nature of its use and occupancy;

5. character of each district and the character of the buildings already erected;

6. the conservation of property values and the direction of building development.

In Britain the collective approach to securing the individual's interest in daylighting has not blurred the functional and systematic method of valuing that was first developed by the Waldrams, John Swarbrick and others for particularized use with the 1832 Prescription Act. The science of daylight, including a well considered conception of daylighting adequacy, was carried over intact into public law. In valuing daylighting local authorities have drawn on the results of continuing physical research and social surveys of existing conditions and the resulting daylighting codes issued by the Codes of Practice Council and published by the British Standards Institution (Ref. 11). For assistance with measuring techniques local authorities have also had the benefit of the work of the Building Research Station of the Department of Scientific and Industrial Research (Ref. 12). In Canada there is no parallel tradition of systematic and scientific valuing for open space control except that of the minimum standards for fire safety (Ref. 13) successfully resolved by the Division of Building Research of the National Research Council.

THE DIRECT AND INDIRECT EXPRESSION OF DAYLIGHTING VALUE

The few development control statements of daylighting value that exist are expressed in either a direct or indirect form. The best example of a direct expression is that of the British daylighting Code (Ref. 14). Values are expressed as qualities and conditions of daylight desired or acceptable indoors. The fact that the values are obtained by manipulating outdoor space and windows according to well known principles of daylighting science is not part of the Code but pertinent recommendations are made (Ref. 15). See Table II.

In contrast, the North American approach to valuing is indirect. Actual open space and areas that are thought to produce desirable or acceptable conditions are specified rather than the conditions themselves. The procedure is through examples or forms of development that are described in the control. Because of the approach all control objectives must be embodied in one space or area specification. Table III is such a comprehensive specification. It describes the proposed form of the residential environment of the City of Boston in one simple specification table.

TABLE II

RECOMMENDED MINIMUM STANDARDS OF DAYLIGHTING FOR DWELLINGS*

Room	Size sq ft	Sky Factor per cent	Penetration	Daylight Area sq ft
Kitchen	up to 100	2	6 ft rising	50
	up to 120	2	in proportion	to
			to 7 ft	60
Living	up to 150	1	8 ft rising	75
Room	up to 200	1	in proportion	to
			to 10 ft	100
Bedroom	up to 120	0.5	9 ft rising	60
	up to 200	0.5	in proportion	to
			to 11 ft	100

Note: These standards are measured at table height (2 ft 6 in)

*Code of Functional Requirements of Buildings. Cp 3: Chap. 1 (A): 1949. Daylight (dwellings and schools).

TABLE III

A DESCRIPTION OF THE PROPOSED FORM OF THE RESIDENTIAL ENVIRONMENT OF THE CITY OF BOSTON PRESENTED TABULARLY AND EMBODYING DESIRED OR ACCEPTABLE DAYLIGHTING VALUES.*

District	Type of Use	LOT SIZE minimum in square feet	LOT AREA min. sq. ft. per dwelling unit in addition to 1	LOT WIDTH minimum in feet	†FLOOR AREA RATIO maximum	HEIGHT OF BUILDINGS maximum: in stories	HEIGHT OF BUILDINGS maximum: in feet	OPEN SPACE min. sq. ft. usable per dwelling unit	FRONT YARD min. depth in feet	SIDE YARD minimum width in feet	REAR YARD min. depth in feet	SETBACK OF PARAPET min. distance from any lot line (See Article 21)
RESIDENCE DISTRICTS												
S-.3	1-family detached	9,000	none	70	0.3	2½	35	none	30	12	50	none
	Other allowed use		6,000						35	15	60	
S-.5	1-family detached	6,000	none	60	0.5	2½	35	none	25	10	40	none
	Other allowed use		4,000						30	12	50	
R-.5	1 & 2 fam. detached	5,000		50	0.5	2½	35	none	20	10	40	none
	Any other dwelling	2 acres	3,000	200		2		1,000	25			
	Other allowed use	5,000		50		2½		none	25			
R-.8	1 & 2 family row	3,000 (semi-detached)	2,000 (attached)	none	0.8	3	35	800	20	10 (semi-det.)	40	none
	Any other dwelling	5,000	1,500	50				800	20	10		
	Other allowed use	5,000	1,500	50				none	25	10		
H-1	1 & 2 family row	2,000 (semi-detached)	1,500 (attached)	none	1.0	none	none	400	20	10 (semi-det.)	30	$\frac{H+L}{6}$
	Any other dwelling	5,000	1,000	50				400	20			
	Other allowed use	5,000	1,000	50				none (See Sec.17-1)	25	$10 + \frac{L}{20}$ (See Sec.19-2)	$10 + \frac{L}{20}$ (See Sec 20-2)	
H-2	Any det. dwelling	5,000	none	none	2.0	none	none	150	20	$10 + \frac{L}{20}$	$10 + \frac{L}{20}$	$\frac{H+L}{6}$
	Any other dwelling	none						150		none		
	Other allowed use	none						none (See Sec.17-1)		none (See Sec.19-2)	(See Sec.20-2)	
H-3	Any det. dwelling	5,000	none	none	3.0	none	none	100	15	$10 + \frac{L}{20}$	$10 + \frac{L}{20}$	$\frac{H+L}{6}$
	Any other dwelling	none						100		none		
	Other allowed use	none						none (See Sec.17-1)		none (See Sec.19-2)	(See Sec.20-2)	
H-4	Any det. dwelling	5,000	none	none	4.0	none	none	50	15	$10 + \frac{L}{20}$	$10 + \frac{L}{20}$	$\frac{H+L}{6}$
	Any other dwelling	none						50		none		
	Other allowed use	none						none (See Sec.17-1)		none (See Sec.19-2)	(See Sec.20-2)	
BUSINESS DISTRICTS												
L-.5	Any dwelling	•	•	•	0.5	2½	35	•	•	(See Sec.19-11) •	(See Sec.20-6) •	none
	Other allowed use	none	none	none				none	15	none	40	
L-1	Any dwelling	•	•	•	1.0	3	35	•	•	•	•	none
	Other allowed use	none	none	none				none	10	none	30	
B-1	Any dwelling	•	•	•	1.0	3	40	•	•	•	•	$\frac{H+L}{6}$
	Other allowed use	none	none	none				none	none	none	$10 + \frac{L}{20}$	
B-2	Any dwelling	•	•	•	2.0	none	none	•	•	•	•	$\frac{H+L}{6}$
	Other allowed use	none	none	none				none	none	none	$10 + \frac{L}{20}$	
B-4	Any dwelling	•	•	•	4.0	none	none	•	•	•	•	$\frac{H+L}{6}$
	Other allowed use	none	none	none				none	none	none	$10 + \frac{L}{20}$	
B-8	Any dwelling	•	•	•	8.0	none	none	•	•	•	•	$\frac{H+L}{7}$
	Other allowed use	none	none	none				none	none	none	$10 + \frac{L}{20}$	
B-10	Any dwelling	•	•	•	10.0	none	none	•	•	•	•	$\frac{H+L}{8}$
	Other allowed use	none	none	none				none	none	none	$10 + \frac{L}{20}$	

* Boston City Planning Board, Proposed Zoning Regulations, Section 13-1, Table B, 1957.

THE BRITISH DAYLIGHTING CODE: DIRECT VALUE EXPRESSION

The Code is not a law but a detailed set of residential daylighting recommendations that are considered adequate. The basis of the Code is the report of 1944 on "The Lighting of Buildings." The main features are:

1. Recommendations are quantified in terms of sky factor, penetration (no skyline), and daylight area for kitchen, living room and bedroom of floor area up to 200 sq ft (see Table II).

2. It is considered that the window that gives the penetration required will, in general, provide the recommended daylight area.

3. Where obstructions or skylines are not of the general case and are complicated, detailed calculation is necessary and may require estimation based on the principles developed for the performance of windows, or on tables giving sky factors in terms of penetration, daylight area and window shape and size, or on Waldram diagram analysis.

The Code considers the main categories in which housing forms might occur: that of parallel rows characteristic of the development of streets, and that of open planning associated with projects built at once over large areas and having more than one building on a lot.

4. Where buildings are sited in parallel rows the Code recommends that a 25-deg vertical angle separate the rows. The angle is drawn from the lowest floor window sill in one row to the top of buildings in the next row.

5. If there are a number of similar buildings on the same site it is recommended that wherever possible siting should provide for gaps in the skyline; to be effective the gaps should grow in

depth as they get narrower and should extend no more than 30 degrees to either side of the normal.

THE INDIRECT EXPRESSION OF DAYLIGHTING VALUES

The traditional way of valuing daylight is to specify a standard indirectly by specifying examples of development thought to embody desirable or acceptable conditions. This is also a natural way of valuing daylight if most of the components of development are established, such as:

1. street pattern,

2. pattern of land subdivision,

3. demand for housing,

4. methods of building,

5. kinds of developers, etc.

Development controls may recognize that these conditions lead to several commonly occurring forms. Perhaps the most unique is the row house, or what amounts to the same thing, the row of attached houses that abut or have no sideyard and take full advantage of the space of the street for daylighting. The antithesis is the free-standing apartment tower or the single-family detached dwelling. Particularly in grid patterns of one building to a plot, the standard of daylighting becomes, almost entirely, a function of the street space and the incidental side and rear spaces that are specified as minimums (e.g., see Table III).

When values are expressed indirectly it is only rarely that a systematic basis for the valuing can be found. The example from the Perth and Fremantle report that follows is such a case. In nearly all instances where kinds of development or sizes and shapes of open space are specified to obtain a standard of daylighting, no idea is given regarding the criteria of the specification. In fact, it is safe to say that specific identified criteria rarely exist. This is so because daylighting objectives and methods for their valuing and control are most often seen not individually but as components of the larger objective to control overcrowding, overbuilding and congestion. For example, the City of Los Angeles repealed all its residential height limits in 1956, and since that time has regulated the form and size of residential open space entirely by front, side and rear yards, minimum lot areas and maximum lot areas per dwelling. There is no reference to daylighting standards except in the most figurative, nominal form. The City of Chicago provides an equal example.

The question naturally arises as to whether daylighting standards can be successfully incorporated in broad density controls. The answer is that it would seem that they can as long as certain conditions such as building types and street and plot patterns can be anticipated. For example, Gordon Stephenson has developed a density and daylighting relationship for a plot or floor area ratio of five for the daylighting control section of his 1955 Plan For The Metropolitan Region; Perth and Fremantle. The relationship, which is only an example, illustrates various combinations of street width and site depth with which it is possible to achieve a floor area ratio of five within a given daylighting standard. Whether density alone can convey anything of daylighting standards seems doubtful except where one merely assumes the use of traditional forms of housing. Some indication of the answer might be given by a recent British Building Research Station survey of space around buildings on high density housing sites; it showed that current British daylighting standards "seemed to affect layout at very high densities (i.e. over say, 150 rooms/acre)," but such an expression is hardly qualified enough to be meaningful.

EXAMPLES OF INDIRECT DAYLIGHTING VALUE EXPRESSION

Several examples of indirect value expression are worth noting because of their clarity and detail.

1. The 1955 report and Plan for the Metropolitan Region; Perth and Fremantle (Ref. 16) contains an approach to valuing that basically amounts to working out the limiting size and shape of the building in which a given adequate daylighting value can be obtained if the building is lit only from the street and rear lane or boundary area. This example is developed for offices, but could apply, at least in principle, to dwellings:

> "Design data for daylighting in Perth is based on a sky luminance of 1,000 ft lamberts per sq ft, a standard obtained for 90 per cent of normal working hours throughout the year.
>
> "Internally a minimum standard illumination value of 7.5 lumens per sq ft is considered sufficient for all ordinary office tasks (and) should be obtainable under all normal circumstances in all parts of any office room up to a depth of 2 ft from the rear wall of the room."

It is noted that given a sky luminance of 1000 lumens and the above lighting requirements, a daylight factor of 0.75 per cent is required. This compares with the British residential daylighting Code if one considers that to attain the same illumination in Britain the daylight factor would be doubled, or, 1.5 per cent. For example, in the British Code kitchens require 2 per cent, living rooms 1 per cent, and bedrooms 0.5 per cent (see Table II). The report continues:

> "Whilst it is unnecessary to stipulate the standard of internal lighting for all office requirements, or to predetermine the architectural design of a new building, certain assumptions have had to be made of average conditions that can reasonably be expected to prevail in new office construction, in order to establish a code which is uniform in its applications:
>
> (a) External sky luminance, 1,000 lum/sq/ft,
> (b) Min. internal illumination, 7.5 lum/sq/ft,
> (c) Reference point, 2 ft from rear wall of room (position of desk at greatest distance from light source), and 2 ft 6 in. from floor (working surface of desk),
> (d) Internal room reflection factors: ceiling - 75 per cent, walls - 50 per cent, floor - 15 per cent,
> (e) Brightness of external and street surfaces equal to 10 per cent of sky brightness,
> (f) Min. room ceiling heights: ground floor - 12 ft 6 in., all upper floors - 9 ft,
> (g) Distance of window head to ceiling level - 6 in.,

(h) Distance of window sill to floor level - 2 ft 6 in.,
(i) Glazed area as percentage of total window wall area - 50 per cent to 60 per cent.*

And from this the example emerges:

" From scientific analysis recently made by the Commonwealth Department of Labour and National Service in Melbourne, it has been shown that where an obstruction angle between buildings is not greater than 45 degrees, and with the above assumed conditions, office rooms may be between 20 ft and 30 ft deep with adequate internal lighting standards. With a central service area not requiring high illumination, building depths of 70 ft to 80 ft are possible (see Figure 21). Architects can take full advantage of front and rear lighting conditions and design buildings to the full width of the site without providing light courts. Daylighting from side walls in normal cases would not be necessary, and any side lighting provided on the site boundary would not impose any limitations to adjoining development."

2. Another example of the street space used to obtain daylighting values occurs in the New Zoning Plan for the District of Columbia (Ref. 17). The substance of the example is that no sideyards be required for some single-family dwelling types and nearly all types of apartment development. The Plan considers the sideyard may be a useless strip of land defining a space too narrow to provide adequate light, air and privacy. The argument is that an improvement would follow if row housing were recommended:

"Row houses have enjoyed a great traditional popularity in Washington, and they are indeed the most efficient and practical form of urban residential development. It would be of considerable benefit to the city if many such houses were built in the future because they are superior to apartment houses in comfort and the provision of private gardens and garages, but are not so wasteful of scarce urban land as the detached house. This dis-

> cussion is apropos of two and three storey row houses only, since the Victorian variety running to 4 and 5 stories does not fare any better than its apartment house cousin"(Ref. 18).
>
> (It is instructive to note that given three-floor row houses with 10-ft floors and without front yards on a 66-ft street an obstruction angle of about 23 degrees is created between the bottom of one row and the top of the row opposite. This is within the 25 degree maximum recommended by the British daylighting Code. It is interesting that the street could, in fact, be narrowed to less than 60 feet without exceeding the British standard. Of course in reality it would have to be established that the values of daylighting represented by this standard are appropriate for this kind of housing in its place.)

FREE STANDING FORMS

The use of row house form enormously simplifies the problem of securing a standard daylighting. The problem of the free standing forms is more difficult because the need to provide open space of adequate shape and scale at all building faces does not fit with the subdivision pattern of central urban land where plots are sized and proportioned for economic rather than functional reasons. The following example is a good illustration of this problem as it occurs in a common type of free standing development that might exist, with minor variation, in any central residential area (Ref. 19):

> The system of control in Vancouver, coupled with the typical apartment area property size has produced a common type of development: A building having two storeys, a basement, 6-ft sideyards, and a central corridor with perhaps eight suites on each floor, with half the suites lighted entirely from the side; that is from a space between the buildings 12 feet wide and (about) 110 feet long.
>
> In summer and with the most favourable orientation, the angles through which sunlight can enter a room

are 4 degrees on each side. This (can) give two periods of 16 minutes of sunlight in the room each day. For a suite facing east or west, there will be only one 16-minute period of sunlight each day. Furthermore such sunlight as does enter will be at such an acute angle as to be almost useless.

This type of development produces substandard basic living conditions. Its present attractiveness to tenants lies solely in the internal fittings and amenities. As these internal fittings wear out, and because the basic requirements of light, air and privacy are lacking, the area will deteriorate into a slum.

(It is instructive to note that dwellings facing the sideyard enjoy an angle of obstruction of about 60 degrees measured at the bottom floor. This is more than twice the 25-degree maximum recommended by the British Code.)

Two techniques are commonly employed to secure a more consistent daylighting standard for free-standing development where the approach to control is indirect. Most controls express daylighting standards by merely graduating, relaxing, or even eliminating light angle requirements, depending on building width in relation to site width or on some ratio of site coverage. A second measure may be to encourage the aggregation of land into larger sites. The first technique is an attempt to express in nominal form the Waldram diagram relation between the values of different shapes of sky of equal area. This relation was first described by Allen and Crompton in Britain in 1947 and forms the basis of the permissible height indicators (Ref. 20). A detailed example of an attempt to express this relation in nominal form follows (Ref. 21):

"Any building which does not occupy the full frontage will give less physical obstruction to buildings on the opposite side of the street. Buildings facing tower or open development would enjoy more daylight and air...Application of the normal 45 degree angle of obstruction would prohibit tower development but where the width of a building is considerably less than the site frontage, allowing daylight and air at each side of the building, the height could be correspondingly increased within certain prescribed limits. "Tower Development" may be defined as any development that has more than 50 per cent of the total floor space area of the building in a tower form that does not extend in width to the side boundaries of the site... It is suggested that the width of the tower is not greater than the horizontal distance from the face of the tower to the plane of the opposite building line, (or, that the width of the tower subtends a maximum angle at the opposite building line of 53 degrees 08 minutes.)"

(The form of development shown in Figure 19 is an example of this expression.)

There are many other incidental control techniques that imply a valuing of daylight. For example, a proposal made for the 1958 San Francisco Zoning Ordinance, section 33 (b), would allow one-family dwellings to be built to the common side line of two adjoining lots if a sideyard having a width of not less than the combined width of the sideyards normally specified for both boundaries is maintained on each lot on the opposite side. In Vancouver, the City Planning Department is considering a bonus system to encourage developers to stagger similar apartment towers alternately to the front and rear of adjoining lots to eliminate the undesirable sideyard space without increasing the minimum lot area requirement. These examples are attempts to eliminate thin slices of outdoor space in a case by case approach.

THE FUNCTIONAL VALUING OF DAYLIGHT

The question is whether there are inherent qualities of daylight that can provide or point out unique functional criteria with which it may be valued.

THE LIMIT OR THRESHOLD OF NATURAL LIGHTING ADEQUACY

Though daylighting is desired in dwellings, there must be some limiting quantities or conditions that represent a threshold beyond which no humanly adequate penetration of or direct access to daylight exists. The British were the first to find such a threshold of adequacy (Ref. 22):

"To an extent which, a priori, is quite surprising, the judgement passed on the natural lighting in a room is independent of the actual illumination and is governed mainly by the ratio of the illumination at different parts of the room to that of external objects seen through the window. A careful survey

> of daylight conditions in offices showed that over a wide range of actual illumination values, the adequacy or inadequacy of natural lighting at any point in a room was closely related to the ratio of the illumination at that point to the outdoor illumination at the same instant, i.e., to the daylight factor."

And,

> "It had been found that when the illumination fell below a certain fraction (0.2 per cent) of the illumination in the open, most people would consider that the natural lighting at that point was inadequate. This limit was rather picturesquely called the "grumble point," and the position of that time in a room which could be traced out by joining all the grumble points, was used as a criterion of the daylight conditions in the room. If the line enclosed a comparatively small area in the neighbourhood of the window, the room was judged to be badly lighted, whereas if the area enclosed was a large fraction of the total floor area, the daylight conditions were considered good."

THE OPTIMUM QUANTITY OR CONDITION OF NATURAL LIGHT

If an adequacy threshold for daylighting exists, then presumably there is an optimum quantity or condition. Some idea of such an optimum can be provided, at least where "seeing" is concerned, by analysis, given the contrast sensitivity of the eye and an assumed reflection factor (Ref. 23).

> "The relation that has been found to prevail is, in general, that as it gets lighter (adaptation brightness rises) contrast sensitivity increases, but between brightnesses of about 20 and 2000 milli-lamberts (about 6 and 600 candles per ft^2) contrast sensitivity is constant; here the effort of seeing is a minimum. With a net reflection factor of 0.5 (a figure that could easily be lower for many residential conditions) this range compares to an illumination of 37 to 3700 ft candles, which is easily attained in daylight outdoors (where illumination is seldom less than 300 ft candles) but may be attained only rarely indoors even with artificial lighting."

Such an observation implies that optimum conditions lie within a range analogous to that experienced outdoors. It seems more important for the purposes of valuing, however, that an optimum condition could lie at many points on a very broad scale. If this is so it follows that in a very general sense (given the correct surface reflection conditions), and as far as "seeing" is concerned, the important value scale for daylight sensibly lies between a threshold of adequacy condition (the grumble point previously referred to) and the area around the lower limit of such an optimum range.

THE VALUING OF DAYLIGHT ACCORDING TO TASK PERFORMANCE

A considerable research effort has been applied to the problem of determining the "best" lighting values, especially for reading and in relation to school lighting; reading in the home is an important value perameter and would not seem to present a different problem. The task value determined for reading pencil writing is now 70 ft candles. The following discussions illustrate the background considerations in determining this value (Ref. 24).

> "In his "quality of light" studies for classroom tasks, Dr. Blackwell analysed 31 samples of handwriting taken from a sixth grade class in Toronto. Each sample was written with a number two pencil on white foolscap paper and with ink on the same kind of paper. For 99 per cent visual efficiency the intensity requirements for the pencil samples ranged from one foot candle to over eighty foot candles. There were several variables which caused this wide range of lighting requirements. Some samples were written large and with bold lines, while at the other extreme, the samples requiring the high illumination had small characters with very fine lines, and in relatively light line quality. For the 40 per cent of the class requiring the highest intensity, the average was found to be 63 ft candles. The 63 figure was rounded off upwards to 70."

UNIFORM OR GLARE-FREE ENVIRONMENT

A consideration as important as the task level itself is that such levels be determined in a uniform or glare-free environment with no high brightnesses toward the eye. Today, there is no physical problem in attaining or approximately attaining such indoor conditions.

OPTIMUM NATURAL LIGHT AND DAYLIGHT LEVELS

Task research takes a very special and detailed view of the needs of "seeing," but does suggest a general conclusion of importance for standards of optimum natural lighting (Ref. 25).

> "The fundamental principle illustrated is that if you want to see as well as you can you need daylight levels.
>
> "For example, you can read a text having a two minute of arc stroke, black on white background, accurately at 90 per cent of the maximum rate with nine ft-candles; at 95 per cent with 22 ft-candles; at 98 per cent with 60 ft-candles; but the maximum rate requires 600 ft-candles. That is, if you want the degree of certainty that is optimum, you need a lighting level in the daylight range.
>
> 'While people do not consciously know this their bodies do. Their bodies respond so favorably as lighting levels go up, and people feel such refreshing certitude in their perceptions, orientation and actions as lighting levels go up, that they will continue to adopt higher levels as fast as they can afford to; up the the point that they can affort to introduce levels indoors characteristic of the daylight range outdoors."

This observation agrees with that of Luckhardt and Kohler cited above. It also makes a compelling appeal to common sense, yet suggests that drastic changes in the siting of buildings would be necessary to achieve the highest of such levels.

In Section Four it is shown that for ground floor rooms facing a 66-ft street and located in three-floor buildings with average 20-ft front yards, instrument readings taken at room centres commonly indicated illumination levels between 15 and 25 lumens per sq ft incident at sill height. The same rooms at ground floor and facing sideyards of 10 to 14 ft commonly enjoyed illumination levels less than 2.5 lumens per sq ft. A calculation of sky factors supported these results. It seems therefore, at least for this

> scale and arrangement of space, that the street has been adequate in providing a standard of daylighting very nearly equal to that of Luckhardt and Kohler's estimation of optimum conditions and very near the above reading standard of 90 per cent. In any event it is established that the traditional sideyard at the above spatial proportion could never yield any of these so-called optimums.

(Other task values for various purposes are contained in I.E.S. Lighting Handbook, Recommended Levels of Illumination, Third Ed., I.E.S., 1958, New York.)

THE LIMITATION OF A FUNCTIONAL APPROACH

The fact that articial light exists in an inexpensive useful form complicates any approach to daylight valuing based soley on functional seeing requirements. Any valuing must now depend on the dual role of artificial and natural light, or on what the British Building Research Station calls permanent supplementary artificial lighting (PSALI) (Ref. 26). The question remains as to the inherent qualities of daylight that will provide or point out unique criteria with which it may be valued.

THE IMPORTANCE OF DAYLIGHTING VALUES

Enough is known to make certain the need for compromise in seeking criteria of value for daylighting. It seems clear that no single approach such as the analysis of existing information can provide a firm basis. It also seems clear that using "danger to health" as a basis is equally fruitless.

> It is interesting to see the concern given the idea of "danger to health" by the authors of the 1916 zoning resolution for New York City. One of the authors, George Ford, describes how faithfully his committee sought a "vital" relation between light and health that "could be used quantitatively in determining the height of buildings and the minimum size of yards and courts and other open spaces" (Ref. 27). None was found. First, the committee narrowed the problem of finding significant criteria for valuing by limiting themselves to matters of security. Next, they were determined to admit only "unequivocal" evidence, (Ref. 28) and finally, the evidence

had to "prove" that a given quantitative standard was valid. The fact that they could find, with this approach, no basis for a quantified daylighting standard presumably came as no surprise for they worked at a time when the end of development law was still limited to matters of safety and security. Today the terms of reference for development law include the securing of livability as well as life (Ref. 29).

In spite of this the idea that the basis for valuing must be found necessarily in criteria of "danger to health" or security is a strong one. The following quotations show how it lingers on (Ref. 30):

"The present (1956) standards for light in the alleys and courts are much lower than for the streets, in the high density (office) districts (in Washington D.C.)."

The author describes the conditions in the alleys (light angles of 81 degrees with 10 per cent of the sky visible) and the notes that "from a human point of view" an angle of light obstruction approaching that required in the street should be specified. But then he decides there is no basis to do so. The basis considered is security. The old argument reappears:

"However, there is no convincing evidence available to show that there is damage to the health of the workers whose offices and shops have windows on the existing narrow alleys and courts. There are in fact thousands of persons who work in interior spaces with only artificial light and ventilation.... The case for an angle of light obstruction requirement in the alleys thus leans on subjective arguments for its results in terms of 'pleasantness,' 'human scale,' and "desirability'."

The author is not really satisfied with his reasons and adds that justice may be done, however indirectly:

"These qualities may be sacrificed in business districts at the discretion of the property owner who suffers economically if he is wrong."

Some measure of the traditional strength of the conception that community interests must be valued according to none but "objective" criteria appears in the same text when the author observes that residential buildings in commercial developments must enjoy the protection of proper light angles, even in the alleys - but not for human reasons (Ref. 31):

"In Washington's moist climate, wooden buildings which receive no direct sunlight are subject to "dry" rot and much more liable to termite attack."

There are many more examples of how the valuing process may avoid any direct contact with the individuals for whom it is supposedly maintained: the users of property.

The British recognized this problem by using a social survey technique in setting up their daylighting standard, commonly known as the daylighting Code (Ref. 32). The technique on which the Code is based incorporates several important ideas:

1. While the roots of the criteria of valuing may be complex or of uncertain form, the problem of assessing values is, of necessity, more simple than this suggests, for the components of light that are measurable are brightness and differential brightness, which is expressed and easily measured by the daylight factor and very nearly by the sky component.

2. If more than functional factors should be accounted for then the only simple, effective and available approach in valuing daylighting is to survey the judgements of people in relation to the adequacy of the conditions they are actually experiencing, and, presumably, the larger the survey the better.

3. Such a survey of judgements is in the nature of an empirical study of existing conditions; it cannot be relied on to "prove" that any value is right, but it can provide a useful and rational way of recommending values that directly "fit" the expressed interest in natural lighting for a given place and housing and spatial conditions.

The social survey technique that the British daylighting standard is based on follows regular principles of procedure statistically and in the choice of a sample, with the investigators being trained observers (Ref. 33).

The initial approach consisted of calculating, according to daylighting theory, the daylight factor, penetration, and daylight area that ought to exist in all kitchens, living rooms and bedrooms of the 62 sample dwellings chosen (Ref. 34). The next step was the actual interview of tenants. The essential features of the survey program are as follows:

1. Moving from room to room in each dwelling, the observers measured by instrument the level of illumination and checked at different locations to see whether any sky could be seen in a mirror laid flat at the point in question.

2. In moving from room to room the observers asked the tenant to judge, at different points, whether he considered he could see well, adequately or badly in relation to penetration and daylight area. In each case the observer recorded his own opinion as very good, good, fair, poor or very poor.

3. Because daylight adequacy is reflected directly in the amount by which natural light is supplemented by artificial light, the observers asked, in each room, whether the tenant used the electric light, never, occasionally or often.

4. Because decorations have a substantial effect on the quality of lighting, the observers analysed them.

5. Because the time of year might have a considerable effect on opinions, both summer and winter judgements were recorded.

6. Opinions were recorded with respect to each room taken as a whole.

7. Opinions were recorded for the kitchen in relation to the work centres at the stove, sink and work-table.

The analysis of the survey rests on the kinds of consensus that developed between the opinions of observer and tenant and where trends of opinion settled in relation to percentages of daylight factor, penetration distance and daylight area. For example (Ref. 35):

> "There is no evidence that people in one block of flats differ from those in another in their general reaction to daylight. In the best lighted estate and in a second rate group, opinions at the sink for a 5 per cent daylight factor show the same dispersal of opinion."

Several important conclusions were drawn from the survey:

1. Opinion showed a convincing trend of improvement with improvement in lighting.

2. The investigators' opinions were found reliable and consistent and corresponded with the tenants.

3. For a daylight factor of 2 per cent in the kitchen the majority found a daylight area of 16 to 20 sq ft to be good.

4. In all instances in kitchens where the penetration of the 2 per cent daylight factor exceeded 5 to 6 ft and the area lighted to this value exceeded 16 sq ft, the room was judged by both tenants and investigators to be well lighted.

5. People confirmed their opinion of daylighting conditions by adding artificial lighting.

6. A large majority felt 2 per cent daylight factor at the stove inadequate, but this seemed satisfactory at the work table and sink.

7. For living and dining rooms a penetration of the 1 per cent daylight factor of 8 to 10 ft seemed to remove the rooms from fair to good. For bedrooms a 0.5 per cent daylight factor, 90 sq ft daylight area, and 8 to 10 ft of penetration were satisfactory.

At the time of this survey daylighting conditions were studied, but in less detail, as part of a larger survey (2375 interviews) of lighting needs in general (Ref. 36). The conclusions reached were that daylighting is significantly more satisfactory than artificial lighting, that higher income groups have better daylighting than do lower income groups, and that most tenants desire sunlight in their sitting rooms during the afternoon.

However limited these surveys may be there can be no doubt of their importance in the process of decision making. The standard derived from them has become an important index of spatial control precisely because its rational and known basis affords a systematic approach for evaluation at any time and allows for revision or adjustment if necessary (Ref. 37).

SUMMARY

The residential indoor provision of daylight is a basic individual and community objective. The problem of valuing is to determine what quantities or conditions of daylighting are acceptable, adequate, or desirable in terms not only of safety and security but also of livability.

Daylight valuing has been accomplished in Britain with the help of special social survey techniques applied to dwellings and offices. This approach is effective because it takes into account several important components of value, vis., the use of rooms, the nature of occupants and their natural bias, and particular, local, or regional housing conditions. Judgements of adequate, inadequate or acceptable daylighting are made not in terms of actual illumination levels but as expressions of indoor-outdoor differential brightness or daylight factor. This is a convenient expression because social survey data can be related directly to data derived from measurement and analysis methods also based on the daylight factor. The British residential daylighting standard is shown in Table II.

Guidance with desirable or optimum daylighting quantities or conditions can be obtained by making use of the extensive data available from research of lighting values for visual task performance. Such research indicates that for the functional purposes of "seeing" daylight levels of illumination (say, 500 lumens / sq ft) are required to take full advantage of the eye.

Daylighting values are expressed either directly as quantities and conditions of indoor daylighting (see Table II), or indirectly as quantities and conditions of open space and as actual forms or types of development believed to embody acceptable or desirable daylighting standards (as shown in Table III). In Britain a good start has been made in developing a direct daylighting standard that is particularly effective for use in "open" planning. Indirect standards present definite opportunities where most of the components of development, such as street and land subdivision patterns, are established.

The main problems that arise in determining a rational and useful daylighting standard are mainly due to the need for compromise in the process of valuing. There is no single criterion to provide the whole basis for a given quantity or condition of daylighting but enough is now known or can be readily known, in a comprehensive way, to provide reasonable support for any valuing decision.

Finally, a most important requisite of an adequate standard is that it can be assessed, altered or adjusted so that it continues to reflect, with the greatest economy and effectiveness, the particular daylighting interest it is designed to secure.

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10. See e.g., Pound, R., An Introduction To The Philosophy Of The Law, Chap. 5.

11. For social surveys of existing conditions see e.g., "The Lighting of Buildings," Report No. 12, (H.M.S.O., 1944) Appendix V, VI; Gray P.G. and Goslett, T. "A Survey of Lighting in Offices," Report No. 30, (H.M.S.O., 1952), Appendix I. For physical research the best summary and reference is Walsh, Science of Daylight. For recommendations that have resulted see e.g., Code of Functional Requirements of Buildings, Chap. I (A). Daylight, B.S.I., London, 1949;

Ministry of Housing and Local Government, "Flats and Houses," (H.M.S.O., 1958), London: Ministry of Housing and Local Government, "The Density of Residential Areas," (H.M.S.O., 1952), London; Hopkinson, R.G., Longmore, J. and Graham, A.M., "Simplified Daylight Tables," Report N. 26, (H.M.S.O., 1958), London; Alan, W. and Crompton, D., A Form of Control of Building Development in terms of Daylighting, R.I.B.A. Journal, 1947; Building Research Station, Principles of Modern Building, Vol. 1, 3rd. edition, (H.M.S.O., 1959), London, Chap. 7; Hopkinson, R.G., Longmore, J., and Petherbridge, P. An Empirical Formula for the Computation of the Indirect Component of Daylight Factor, Trans. Illum., Eng. Soc. 19, 201, 1954; Sheppard, R. and Wright H., Building For Daylight, London, Allen and Unwin, 1948.

12. The method of most importance is fully described by: Allen and Crompton, Form of Control in Terms of Daylighting.
    See also: Walsh, Science of Daylight, Chap. 9 and 10.

13. See e.g., McGuire, J.H., "Spatial Separation of Buildings" Ottawa, National Research Council, Division of Building Research, Internal Report, No. 187, 1959.
    See also: Shorter, G.W., "St. Lawrence Burns General Report" Ottawa, National Research Council, Division of Building Research, Internal Report No. 150, 1959; National Research Council, Associate Committee on the National Building Code, Housing Standards, 1963. Supplement No. 5 to the National Building Code of Canada, Ottawa, Sec. 9.3.3:4.3.

14. Code of Functional Requirements of Buildings, Chap. 1 (A) Daylight.

15. Ministry of Housing and Local Government, "Flats and Houses," (H.M.S.O., 1958), London.

16. Stephenson, G., and Hepburn, J.A., Plan For The Metropolitan Region: Perth and Fremantle, Government of Western Australia, 1955, Appendix I and III.

17. Lewis, H.M., A New Zoning Plan for the District of Columbia, Commissioners of the District of Columbia, 1955.

18. Ibid., p. 32.

19. City Planning Department, Vancouver, Explanation of the Daylight Access Regulations of the Apartment Section, Proposed Revised Zoning By-law, Vancouver, 1955, p. 2.

20. Allen and Crompton, Form of Control in Terms of Daylighting.

21. Stephenson and Hepburn, Plan For The Metropolitan Region; Perth and Fremantle. p. 295.

    There are, of course, many other examples of the recognition of this fact. The one cited is merely representative and reasonably faithful to the fact.

22. Walsh, Science of Daylight, p. 4.

23. See also: Luckhardt W. and Kohler, W., Lighting in Architecture. N.Y., Reinhold, 1959, p. 124, who suggest this figure.

24. Crouch, C.L., Building Illumination, the Effect of New Lighting Levels, "The New I.E.S. Recommended Levels of Illumination," National Academy of Sciences, National Research Council, Washington, D.C., Publication 744, 1959, pp. 18, 23.

25. Ibid., p. 35.

26. Hopkinson, G. and Longmore, J., The Permanent Supplementary Artificial Lighting Of Interiors, Trans. Illum. Eng. Soc. (Britain, 1959), 24, 121.

27. Ford, Building Height, Bulk and Form, p. 72.

28. Ibid., p. 73.

29. This is often disputed but the terms of provincial enabling legislation certainly allow reasons of livability, e.g., "promotion of public health, safety, convenience and welfare. Moreover, the meaning of safety and security is hard to define for threats to safety and security can develop for various reasons, often complex. The question raised is where the dividing line lies between security and utility and whether it can always be located by simple figurative, nominal means in a contemporary urban community.

30. Lewis, Zoning Plan for the District of Columbia, p. 55.

31. Ibid.

32. British Standard Code of Practice, Cp. 3, Chap. 1 (A), 1949. Daylight (Dwellings and Schools) British Standards Institute, London.

33. The Lighting of Buildings, Report No. 12. (H.M.S.O., 1944), Appendix V and VI.

34. Ibid., p. 62.

35. Ibid., pp. 104, 105.

36. Ibid., pp. 110, 132, 138.

37. The standard has been under review at different times. See e.g., Walsh, The Science of Daylight, p. 229.

PART FOUR: A FIELD STUDY OF DAYLIGHTING

This study is an attempt to demonstrate, by example, the application of a measurement program based on the idea of an integrated physical and social study of daylighting. The program consists mainly of the three available methods of measuring daylighting, viz., graphic analysis, instrument, and soliciting the judgements of occupants. Physical measurement is accomplished by instrument or light meter study and by Waldram graphic analysis. Social measurement consists of a household survey and questioning of tenants. The comparison of data derived from all three approaches could ultimately form the basis of a daylighting standard that would have an acceptable, useful systematic basis (Ref. 1). The survey is also intended to test the effectiveness of the interview method and the questionnaire in gathering subjective impressions and objective observations of daylighting conditions, electric light use, aspect, view, orientation, visual privacy and insolation. An over-all objective is to provide detailed information concerning problems that might arise in applying a full social survey of daylighting conditions.

SCOPE OF THE STUDY

The study was concerned with the following:

1. A detailed analysis by Waldram diagram of daylighting in kitchens, bedrooms and living rooms.

2. A light meter measurement of daylight in the centre of kitchens, bedrooms and living rooms.

3. How well the tenants or occupants could see by daylight and whether they considered the available natural lighting adequate for normal use of the room.

4. To what extent the respondents found it necessary to supplement their daylighting with electric light.

5. How the main rooms received sunlight and the respondents' preferences for sunlight and daylight.

6. How the respondents regarded their views and orientations (north, south, east, west) and what orientations they preferred.

7. The nature of each respondent including his family status, occupation and housing history.

THE UNIT OF MEASUREMENT USED IN THE STUDY

The study is based on the daylight factor as a unit of measurement. The underlying hypothesis indicated by British experience (Ref. 2) is that integration of measurement criteria is possible because the index of daylighting is expressed both subjectively and objectively. This convenience comes about, first, because the index is a ratio of simultaneous indoor to outdoor illumination that is directly related to the amount of sky visible from indoors, and hence, to the physical relationships of space defined by openings and obstructions. Second, differential brightness is a basic sensitivity of the eye. As a result, the daylight factor is a direct, sensitive and comparative unit of measure for natural lighting.

THE STUDY AREA

Before a final choice of study area was made three areas were considered:

1. A flat suburban area of similar, new and widely spaced single-family dwellings with fairly uniform skyline (Figure 22).

2. A hilly urban area of differing, old and closely spaced single-family dwellings with heavy growth (Figure 23).

3. A downtown multiple-family dwelling area of closely spaced, similar, old and new three-floor apartment buildings containing suites with a variety of outlook and exposure (Figure 24).

The method of comparison consists of calculating, according to daylighting tables, the sky components and internal and external reflected components obtained in a representative habitable room that is considered to exist at one typical ground floor location in each of the study areas. The room orientations studied are:

1. to the street

2. to the sideyard,

3. to the backyard or rear area.

The characteristics of the room are:

1. floor area is about 100 sq ft,

2. ceiling height is 8 ft,

3. the window is in the centre of one wall, sill height is 2 ft 6 in. above the floor, head height is 7 ft 6 in., window width is 4 ft 6 in.

4. The reference point for daylight measurement is 2 ft 6 in. above the floor and 6 ft from the centre of the window. The vertical angle from the reference point to the window head is 0.

The daylighting tables and calculation notations used are those of:

Hopkinson, R.G., J. Longmore, and A.M. Graham, "Simplified Daylight Tables," Report No. 26, (H.M.S.O., 1958).

Before considering each site it is helpful to know the values for the following:

1. Sky component for the fully unobstructed window = 3.2 per cent.

2. External reflected component for the fully obstructed window = 0.6 per cent.

3. Internal reflected component = 0.1 per cent.

1. SUBURBAN AREA CALCULATION

After an examination of the area the skyline was considered uniform because of low prevailing angles of obstruction, the nearly equal height and form of buildings, their juxtaposition and vegetation.

This assumption leads to considerable simplification.

Aspect to the street:

The effective height of houses = 18 ft (H_1)
A representative distance from reference point to skyline = 138 ft (D_1):
H_1/D_1 = 18/138 = 0.1 per cent
W_1/D = 0.4 ooooo not significant
Daylight factor assumed as 3.3 per cent

Aspect to the sideyard:

A representative distance from reference point to skyline = 24 ft:
H_1/D_1 = 18/24 = 0.8 per cent
H/D = 0.833 ooo almost totally obstructed
Daylight factor assumed as 0.7 per cent

Aspect to the rear yard:

A representative distance from reference point to skyline = 80 ft:
H_1/D_1 = 18/80 = 0.2 per cent
W_1/D = 0.4; component = 0.2 per cent
Daylight factor = 3.3-0.2+0.2/5 = 3.1 per cent

2. HILLY URBAN AREA CALCULATIONS

These calculations reflect the worst effect of slopes that vary from 10 to 20 per cent.

Aspect to the street:

H_1/D_1 = 43/170 = 0.3
W_1/D = 0.4
Daylight factor = 3.3-0.3+0.3/5 = 3.1 per cent

Aspect to sideyard:

H_1/D_1 = 25/32
W_1/D_1 = 0.4 oooo totally obstructed
Daylight factor = 0.7 per cent

Aspect to the rear yard:

The effect of topography is such that this aspect is either fully unobstructed or fully obstructed.

3. DOWNTOWN AREA CALCULATIONS

Though the effective height of buildings varies the representative height used is 27.5 ft. The skyline is assumed to be uniform, with the representative room at ground floor level:

Aspect to the street:

$H_1/D_1 = 27.5/128 = 0.2$
$W_1/D = 0.4$
Daylight factor = 3.3-0.1+0.1/5 = 3.2 per cent

Aspect to the sideyard:

Totally obstructed; Daylight factor = 0.7 per cent

Aspect to the rear yard:

$H_1/D_1 = 27.5/70 = 0.4$
$W_1/D = 0.4$
Daylight factor = 3.3-0.4+0.4/5 = 3.0 per cent

This very limited examination reveals that ground floor rooms in these three areas enjoy substantially unobstructed aspects to front and rear areas. In each case, however, aspects to the sideyards are substantially or fully obstructed. In the two areas of single-family detached dwellings this full or substantially full sideyard obstruction means that only part, usually a small part, of the dwelling unit is so obstructed, but for the downtown apartment building area fully half the dwelling units in any building have a complete sideyard exposure and thus may be expected to enjoy a range of fairly low daylight factors. For this reason the downtown apartment area might provide the widest variety of daylighting conditions.

The downtown study area was not chosen as a statistically ideal sample but as a group of urban dwellings representing a common urban siting pattern ranging between very bad and very good indoor daylighting conditions.

The desirable buildings that could be chosen for study (Ref. 3) are shown on the plan of Figure 25. Figures 26-29 show the typical floor plan of each building; Table IV sets out the number of apartments in relation to floor level and building. Table V contains comparative physical criteria for each building.

TABLE IV

NUMBER OF APARTMENTS IN RELATION TO FLOOR LEVEL AND BUILDING NUMBER*

	Basement	First Floor	Second Floor	Third Floor	Apartment Building Totals
Building 1	4	8	8	8	28
Building 10	Nil	9	9	9	27
Building 11	3	6	6	6	21
Building 12	2	12	12	12	38
Totals by Floor Level	9	35	35	35	

*See Figure 25 for building positions.

TABLE V

COMPARATIVE PHYSICAL CRITERIA FOR THE STUDY AREA

	Building 1	Building 10	Building 11	Building 12
Built	1925	1953	1931	1930
Architect,	Yes	Yes	Yes	Yes
Lot Size	52'x131'	66'x131'	66'x131'	132'x131'
Lot Acres	0.16	0.19	0.19	0.39
Lot Coverage	91%	70%	70%	59%
F.A.R.	3.6	2.5	2.5	2.1
Dwellings	28	27	21	38
Density*	175	147	147	72
Floors**	4	3.5	3.5	3.5
Front Yard	Nil	11'	17'	13', 40'
Side Yard	Nil	4', 3'	5', 7'	7', 6'
Rear Yard	Nil	10'	16'	16', 40'
Av. Dwelling Area***	440 sq ft	470 sq ft	650 sq ft	550 sq ft

* Density unit is dwellings per acre
** Includes floors substantially above grade
*** Average dwelling area excluding public halls and stairs

QUESTIONNAIRE

The form of the questionnaire is designed to meet the main aims of the study: the subjective judgement of daylighting and related conditions. In designing the schedule the British "Lighting of Buildings" report proved helpful. The form of the schedule was finalized after it was tested on ten respondents and then adjusted, with the help of a consultant (Ref. 4), to a more suitable content and arrangement.

It was recognized that personal judgements of daylighting adequacy might be based on more than functional seeing requirements. To accommodate inaccuracies the allowance for the "spectrum" of response was widened, first, by adding questions about conditions related to daylighting which include view, orientation, insolation, and electric light use, and second, by using both "open" and "choice of answer" approaches. This procedure promised to be of greatest benefit if the study was used as the basis for a large social survey.

The test of the questionnaire indicated that it was more accurate for the interviewer to record instrument readings of illumination and judge the daylighting adequacy himself while moving from room to room, as well as questioning the respondent. Questions 1, 2 and 3 were designed accordingly.

A number of questions were included to provide a check on the basic lighting adequacy questions and to stimulate recall or more thoughtful consideration. Question 5, the use of electric light, is the main check. Questions 4, 7 and 9 were included primarily to expand the "spectrum" of response and question 6 was included mainly to provide a break.

The schedule was designed for a 15- to 20-min interview. Appendix B contains the final form of the schedule.

COOPERATION OF RESPONDENTS

Two unanticipated complications arose in securing the cooperation of respondents. The first was the need for overcast weather for light meter readings at the time of interview; the second was the unfortunate coincidence of a well-publicized crime wave in the neighbourhood of the study area (Ref. 5).

In approaching the tenants the janitors of the buildings were asked to advise them that the study was legitimate, and a duplicated letter was mailed before the interviewer finally made a personal call.

Although the over-all response is 46 per cent, the actual response should be adjusted upwards to, approximately, 54 per cent because the study stopped before tenants on the upper floors of building No. 12 were fully canvassed. The degree of response is shown on Table VI.

The outstanding feature of the pattern of response is the high degree of cooperation received from tenants on lower floors. It seems that tenants on upper floors are harder to find and less cooperative. A probable explanation is that most lower floor tenants are retired. (See Nature of Respondents.)

The exact meaning of cooperation has special importance. The 46 per cent figure does not reflect the number of tenants who agreed to be interviewed and then refused any inspection, particularly of bedrooms (Ref. 6). There were many degrees of cooperation beyond the tenant's figurative agreement to permit the study. Most tenants with poor daylighting were, as might be expected, most articulate and generous with comment, and for those enjoying good daylighting, the reverse was true.

THE NATURE OF RESPONDENTS

The distinctive characteristic of the cooperating study group is the large number of retired respondents (Table VII). By comparison with three other occupational groupings and in relation to floor level, they occupy the majority of ground floor dwellings (61 per cent), half the second floor dwellings, and 37 per cent of third floor dwellings. These high proportions might be explained by the possibility that the composition of the cooperating group was biased in the direction of those naturally home most of the time. An examination of the total dwellings of retired tenants among the four buildings does not, however, support this possibility. Table VIII shows that the pattern for this study group is essentially consistent with the pattern for the whole study area or for all dwellings in the four buildings.

TABLE VI

TENANTS WHO COOPERATED: FLOOR LEVEL AND BUILDING NUMBER*

	Basement	First Floor	Second Floor	Third Floor	Per Cent By Building
Building 1	4	4	4	4	61 (23)
Building 10	Nil	6	3	5	56 (28)
Building 11	2	4	2	3	58 (5)
Building 12	2	6	Nil	3	32 (12)
Totals by Floor Level	8	20	9	15	
Per Cent By Floor Level	89 (Nil)	57 (23)	26 (14)	43 (14)	

Total Number of dwellings available - 114

Total Number of Dwellings cooperating - 52

Percentage of dwellings cooperating - 46

Percentage of dwellings refusing - 18

*Refusals are shown in brackets.

TABLE VII

OCCUPANCY AND OCCUPATIONAL GROUPS AMONG COOPERATING TENANTS*

	Basement	First Floor	Second Floor	Third Floor	Totals
Dwellings with one tenant	4	2	3	3	12
Dwellings with 2 or more tenants	5	16	6	12	39
Dwellings with school age children	3	3	Nil	2	8
Professional and managerial	Nil	1	2	4	7 (14%)
Clerical and artisans	5	3	1	5	14 (27%)
Labour	4	3	1	1	9 (17%)
Retired	1	11	4	6	22 (42%)

*The occupational groups refer to the ones providing the main support of the dwelling.

TABLE VIII

DISTRIBUTION BY FLOOR LEVEL OF ALL DWELLINGS OF RETIRED TENANTS IN THE FOUR STUDY AREA BUILDINGS*

	Basement	First Floor	Second Floor	Third Floor	Totals
Total dwellings of retired tenants	1	19	10	9	39
As a percentage of total dwellings on each floor	11	54	29	26	34

*Buildings 1, 10, 11 and 12.

The choice of the four occupational groupings used in Table VII was based on whether the groupings might reflect the use of space and the daylighting needs of the respondents rather than "class," wealth, or standard of living (Ref. 7). There are few dwellings with school-age children because of an implied owner policy not to cater to such families (Ref. 8).

Tenants in the downtown district of the study area are highly mobile. City of Vancouver legal department records indicated a district rate of apartment turnover of 50 to 60 per cent, the highest rate in the city. According to question 8 - "What kind of housing did you have before coming here?" - 23 per cent lived in houses, 71 per cent lived in apartments, and 6 per cent had other forms of accommodation. The largest group of respondents (48 per cent) found their housing better compared with 37 per cent who found it worse (see Table IX).

Because question 8 was a partly "open" question it was possible to gather some of the respondent's reasons for comparisons:

1. For example, 60 per cent of those who had previously lived in houses found their apartments worse. Table IX shows that the largest part of this group (58 per cent) moved to first floor dwellings. Further analysis of the open answers indicated that this group was largely retired and had given up their homes because they were too old to maintain them. They had located at ground floor level because their age allowed few steps. Their discontent resulted from their failure to find any variety of apartments with adequate amenity at that level. Many were forced to live at ground floor levels facing entirely into sideyards. They were discontented because their few remaining activities were reading and writing. Evidently, old eyes have particular need of the high illumination levels practically obtained only with daylighting (Ref. 9).

2. Generally, people who had moved from other apartments to upper floors improved their conditions (70 per cent). Of the reasons given for improvement, daylight, view and sun were particularly mentioned.

TABLE IX

WHERE RESPONDENTS LIVED BEFORE MOVING TO ADDRESSES OCCUPIED AT THE TIME OF THE STUDY AND HOW THEY COMPARED THEIR IMMEDIATE ADDRESSES WITH PREVIOUS ADDRESSES

	Basement	First Floor	Second Floor	Third Floor	Totals and Percentages
Lived in house before	1	7	2	2	12 (23%)
Lived in apartment before	7	11	6	13	37 (71%)
Other	1	2	Nil	Nil	3 (6%)
Totals	9	20	8	15	52
Present address better	3	9	5	8	25 (48%)
Present address the same	1	2	2	3	8 (15%)
Present address worse	4	10	1	4	19 (37%)
Totals	8	21	8	15	52

3. Of those who claimed an improvement after moving to lower floors (40 per cent), most gave lower rent or the lack of stairs as the reason. Those who found their accommodation worse (48 per cent) generally found it so because of poor daylighting, lack of sun, view and openness.

ARRANGEMENT OF DATA

The most meaningful variables for the presentation of interview and analysis data were considered to be the relative height of a dwelling by floor level, in some cases by the particular room in the dwelling, and whether the dwelling or room faced a street, sideyard or lane. The Tables of daylight factor, penetration, obstruction distance, etc., include these variables and are drawn to the same format to permit comparison. Where appropriate, selected comment from the open sections of questions is included with the Tables and general discussion.

ANALYSIS OF INDOOR DAYLIGHTING

Indoor daylighting was analysed by obtaining daylight factors from Waldram diagrams (Ref. 10) drawn 30 in. above the floor at the centre points of all kitchens, bedrooms and living rooms (396) in the study area. In addition, a selected group of these rooms (22) from six apartments that represented common conditions were similarly studied at five points (Ref. 11) so that daylight curves could be drawn.

To obtain a reasonable idea of the standard of daylighting in the 396 kitchens, bedrooms and living rooms examined in the four buildings of the study area the British daylight code requirements for daylight factor were superimposed on the Waldram diagram data produced by the analysis. The regions of inadequacy so defined are set out in Table X. According to the British standard almost half the rooms are inadequate (47 per cent). By floor level this region contains 56 per cent basement rooms, 58 per cent first floor rooms, 47 per cent second floor rooms, and 39 per cent third floor rooms. Of all such inadequate rooms, 72 per cent are lit from sideyards, 15 per cent from lanes, and 13 per cent from roads.

Although it is already clear that the over-all daylighting standard is shockingly low, a better view of the problem can be obtained by examining daylighting curves drawn for the selected group of rooms from the six apartments that represent common conditions of location, height and orientation. In each case the curves of Figures 30 to 35 are plotted from three points spaced evenly on an axis drawn normal to the window wall with the centre point located in the centre of the room. These figures clearly illustrate the very inferior daylighting conditions obtained from sideyard orientation and the substantially better conditions obtained from the space of the street or lane.

MEASUREMENT OF INDOOR DAYLIGHTING BY METER

Light meter readings were obtained before and after each interview at a park adjoining the study area (Ref. 12) Readings obtained during each interview were recorded 30 in. above the floor at room centres and were used with the average of the outdoor readings to obtain daylight factors (Ref. 13). This procedure was considered a reasonable compromise in view of the interview problems and the sensitivity of the study.

The measured daylight factors, up to the second floor levels, essentially parallel the distribution of calculated daylight factors, but above this point there is no evident similarity of distribution. There may be several reasons for the variation. The most probable is the variety of window covering and room decor encountered. For example, it was observed that by closing venetian blinds the level of illumination incident at room centres could be reduced by more than 75 per cent. A main limitation of meter data arises from the lack of readings. Forty-two per cent of those who cooperated refused access to one or more rooms. In assessing the meter data the British daylighting Code was again superimposed on the results. The regions of inadequacy so defined are set out in Table XI.

JUDGEMENT OF INDOOR DAYLIGHTING

Judgements of daylighting were made by choice of answer and by discussion (see questions 1-3, Appendix B). Respondents were asked to choose between three simple categories of "good," "adequate," and "unsatisfactory." Unsatisfactory was intended to represent a positive judgement of inadequacy; adequate, an expression of indifference; and good, a positive expression of satisfaction. The important difference in valuing was considered

TABLE X

DAYLIGHT FACTORS OBTAINED BY WALDRAM DIAGRAM FOR ALL ROOMS (396) IN THE STUDY AREA

Rooms below British daylight standard stated in terms of daylight factor		47 per cent
Inadequately* lit rooms	in basements	56 per cent
	on first floors	58 per cent
	on second floors	47 per cent
	on third floors	39 per cent
Inadequately lit rooms	facing sideyards	72 per cent
	facing lanes	15 per cent
	facing roads	13 per cent
Inadequately lit rooms:	kitchens	82 per cent
	living rooms	41 per cent
	bedrooms	14 per cent

*In terms of British daylight standard.

TABLE XI

DAYLIGHT FACTORS OBTAINED BY LIGHT METER READINGS FOR 120 ROOMS IN THE STUDY AREA

Rooms below British daylight standard stated in terms of daylight factor		37 per cent
Inadequately lit rooms	in basements	50 per cent
	on first floors	53 per cent
	on second floors	14 per cent
	on third floors	13 per cent
Inadequately lit rooms	facing sideyards	57 per cent
	facing lanes	37 per cent
	facing roads	21 per cent
Inadequately lit rooms:	kitchens	43 per cent
	living rooms	28 per cent
	bedrooms	15 per cent

to exist between unsatisfactory judgements and judgements of "adequate" and "good." The main conclusions from questions one to three are:

1. Most rooms facing sideyards were positively judged unsatisfactory (52 per cent). This compares with only 23 per cent of the rooms facing lanes and 11 per cent facing streets.

2. Most basement rooms were positively judged unsatisfactory (56 per cent). This compares with 34 per cent on the first floor, 20 per cent on the second and 18 per cent on the third.

3. The most unsatisfactory room was the kitchen. Of all kitchens, 52 per cent were positively judged unsatisfactory. By comparison, most living rooms and bedrooms were judged adequate or good, (76 per cent of living rooms and 83 per cent of bedrooms).

The distribution of judgements is shown in Table XII.

Another way of assessing the judgements of respondents is to compare them with judgements made at the same time by the interviewer. This comparison shows a close coincidence:

Percentage of rooms facing sideyards in which daylighting was judged inadequate:
52 per cent by interviewer
54 per cent by respondent

Percentage of rooms facing lanes:
20 per cent by interviewer
23 per cent by respondent

Percentage of rooms facing roads:
13 per cent by interviewer
11 per cent by respondent

TABLE XII

TENANT JUDGEMENTS OF THE ADEQUACY OF DAYLIGHTING IN KITCHENS, BEDROOMS AND LIVING ROOMS (149 ROOMS)

Rooms with daylighting positively judged inadequate		31 per cent
Rooms positively judged inadequate	in basements	56 per cent
	on first floors	34 per cent
	on second floors	20 per cent
	on third floors	18 per cent
Rooms positively judged inadequate	facing sideyards	52 per cent
	facing lanes	23 per cent
	facing roads	11 per cent
Rooms positively judged inadequate:	kitchens	52 per cent
	living rooms	24 per cent
	bedrooms	17 per cent

A selection of respondent's comments that are representative of the data of Table XII follow:

1. A retired woman at first floor level facing a sideyard. Measured daylight factor for living room = less than 0.5 per cent: "Can't see a thing in here without the light. I look at T.V. all day. When you're on Old Age Pension you take what you can get. On some of the dark days I would say to Jack (her son), - turn on those lights, I can't see you there."

2. A widow at third floor level facing a sideyard, measured daylight factor for living room = 6 per cent: "I don't find it light enough in here. I would like to open the curtains wide but I can't."

3. A spinster at ground floor level facing a sideyard, measured daylight factor for living room = could not be measured: "When people come in they remark how dark it is. If it's a dark day its really depressing. On a wet day it's really dark."

4. A retired husband at ground floor level facing a lane. Measured daylight factor for living room = 3 per cent: "I would say inadequate for all activities. They got more light (pointing to a new tall building across the lane) but I don't want to live in one of those shredded wheat boxes. I often sit here and watch it get darker if a flock of white clouds moves away leaving the blue sky. It's much brighter if the sun shines on the white clouds."

5. Retired widow at third floor level facing a lane. Measured daylight factor for kitchen = 1 per cent: "Its as good as any could be but to work at the range you need the light on. You can't see in the cupboards or read a recipe without the light."

6. Husband, salesman, at first floor level facing a road. Measured daylight factor in living room = 3 per cent: "We are all right on the front here even on a dull day, - even if you went to the back of the room there."

7. Widow at ground floor level facing road. Measured daylight factor in living room = 1 per cent: "The tree makes things very dark. If I read I go to a room without a tree. That room (bedroom) is so dismal I won't furnish it. It's hopeless - it's a dump. I have a daughter and they won't rent all the one up there (upstairs on first floor) but they rent it to

those old bastards and they tramp around in their leather shoes - so to hell with them."

DAYTIME USE OF ELECTRIC LIGHT

Respondents were asked how often they found it necessary to use electric light in the different rooms during summer and winter. This question was included as a check on the basic adequacy of daylight, questions (1, 2, 3). It's limitation is its total reliance on the respondent's recall. The offered choice of the answers "rarely," "occasionally" and "most of the time" were intended to parallel the judgement choices of "good," "adequate" and "unsatisfactory" for daylighting conditions. The results are as follows:

1. Most rooms oriented to sideyards (66 per cent) required electric light most of the time. This compares with 10 per cent for lane-oriented rooms, and 20 per cent for road-oriented rooms.

2. Most basement rooms (56 per cent) needed electric light most of the time. This compares with 42 per cent for first floor rooms, 48 per cent for second floor rooms, and 29 per cent for third floor rooms.

3. Most of the kitchens (58 per cent) required electric light most of the time. This compares with 36 per cent for bedrooms, and 22 per cent for living rooms.

The results for winter and summer questioning were not sufficiently complete for presentation.

Over-all, 38 per cent of all rooms required electric light most of the time, and 49 per cent of those that did were kitchens. These results are much the same as those for the judgement of daylight adequacy and indicate that people tend to confirm their judgements of daylight by their use of electric light.

PENETRATION

During the Waldram diagram analysis of all apartments in the study area it was possible to record penetration or "no sky line" distances. By applying the British daylighting standards for penetration another basis for assessing the daylighting quality of the dwellings was established. The region of inadequacy for penetrations that can be compared with Table X contains 33 per cent of all rooms. By floor level this region contains 11 per cent basement rooms, 44 per cent first floor rooms, 29 per cent second floor rooms, and 16 per cent third floor rooms. Of all such inadequate rooms 98 per cent are lit from sideyards and 2 per cent from lanes.

JUDGEMENTS OF SOME COMPONENTS OF ASPECT

Because daylight valuing is based on more than functional "seeing" criteria, several questions were included to gather impressions of the importance of sunlight, view, and orientation (see Appendix B, questions 6, 7, 9, 10 and 11).

In question 6, respondents were asked whether they had usuable outdoor spaces on the property or building to determine the tenants' attitude towards their contact with outdoor space and whether they valued access to natural light.

No provision was made anywhere in the study area for usable outdoor space except on the roof of one building where smoke from a neighbouring garbage burner created an objectionable condition. Respondents varied widely in their regard for usable outdoor space. For example:

1. A retired bachelor at third floor level: "This place is only a garage. That's the kind of thinking we have got to get out of. You live in a beehive and fly away to get honey. But I disagree with sunbathing - its indecent.

2. A middle-aged mother at ground floor level: "No - we only got the front steps. That's one of my gripes - when we came here they told us to keep off the grass."

3. A housewife at ground floor level: "Oh, I suppose I could sit outside there between those buildings. It would be outside but you'd sit under all those windows."

4. A secretary at third floor level: "There is a roof but it's not fixed up. I have been there three times in two years. The smell from the chimney is terrific. If I had a balcony I would use it."

Questions seven and nine were asked in order to determine which room was most important in terms of natural lighting and sun-lighting. In both cases the living room was chosen nearly without exception. It is particularly instructive to note that most tenants regarded kitchens as inadequately lit, but only one respondent chose the kitchen in either question 7 or question 9.

Question 10 was included, in part, as a check on judgements of daylight adequacy. In general, the respondents indicated the following orientation preferences:

North	35 per cent
South	38 per cent
East	12 per cent
West	15 per cent

Of total respondents in the study group 44 per cent desired some orientation other than that they enjoyed. Sixty per cent of respondents oriented to sideyards wanted to change their orientation, and 40 per cent of this group wanted to change to south, in most cases to find the sun.

Those desiring a northern exposure in most cases wanted the view; in the extreme minority, they wished to escape the heat of the sun. According to floor level, those discontented with their orientations are as follows:

basement	50 per cent
first floor	66 per cent
second floor	33 per cent
third floor	27 per cent

On the basis of this sample it would seem there is no doubt that sunlight and view, in that order, are the strong orientation desires.

Question 11 was designed to obtain as direct an answer as possible to the question of view. The results indicate that people react as might be expected from questions already analysed. In general, the results were as follows:

1. The respondents found a sideyard view at a lower level unacceptable.

2. Most good views look to roads from upper floors, reflecting the desire for "openness."

Much of the reaction to this question was mixed because the question was put entirely in "open" form. The following are comments selected at random:

1. Retired husband, at second floor level with view to lane: "We would only be looking at buildings anyway. Just so long as you don't lose your light."

2. Labourer at second floor level with view to sideyard. "We got no view. We only see the neighbours. They should build apartment blocks for kids. Not a thing I like about it."

3. Policeman at third floor level with view to road: "When I came to rent this place I either liked it or I didn't. I remember it was a rather pleasant view."

4. Retired spinster at third floor level with view to lane: "I would think it couldn't be very much worse. We had a bit of the mountains before they built those buildings, but I can walk anywhere."

5. Housewife at third floor level on sideyard: "Uninspiring - depressing. I could gaze at hills. View means a lot to me. I always feel sorry for those who have a view and say nothing. We have only one factor in choosing an apartment. It can't be more than $75, but we wouldn't want this again with them looking in. I can stand and look at the sea for hours; it fills me with awe."

TENANT PROBLEMS AND COMPLAINTS

No questions were asked about specific problems that might affect daylighting, but an attempt was made to locate them by examining the open answers for all questions. The conclusions are as follows:

1. The need for visual privacy appeared to create a major daylighting problem over and above that already present in such spaces as side-yards where privacy problems naturally arise. Tenants covered their windows to obtain privacy at the expense of daylight. This conflict has a parallel in noise control where the tenant's operation of personal restraint may create for him an extreme hardship through loss of his privacy.

2. A number of tenants with southern exposures complained of sun heat. Unlike the problems of privacy, control of the sun did not seem to present a problem for daylighting.

3. Dirt from chimneys was a common complaint, due evidently to one building adjacent to the study group.

COMPARISON OF RESULTS

This study is an attempt to demonstrate, by example, the application of a measurement program based on the idea of an integrated physical and social study of daylighting. The program consisted mainly of the three available methods of measuring daylighting, viz., by graphic or Waldram analysis, by instrument or light meter, and by soliciting the judgements of occupants. Although each of the three methods approaches measurement differently and each measures something different, the combined results of the three approaches should be a reasonable basis for assessing the value of daylighting, and ultimately, for determining an acceptable standard of residential daylighting. At this time the most important aspect of the study is to determine how the three approaches compare.

The first consideration is the number of completely measured rooms. Only those that have been judged by the tenants, analysed by Waldram analysis, and measured by light meter may be considered. For the study group the total is 36. The second consideration is that only rooms of the same type may be compared, e.g. kitchens with kitchens, etc. Accordingly, a breakdown of the 36-room sample by room type follows:

ROOM TYPE	PERCENTAGE OF SAMPLE
kitchens	61
living rooms	30
bedrooms	9
TOTAL	100 per cent

These figures clearly reflect the 42 per cent of respondents who refused full inspection and survey of all of their rooms.

Although a number of approaches are possible in comparing the three methods of measurement, it seems most reasonable to take judgements of daylight adequacy as a basis and then to try to determine how, for example, the meter and Waldram diagram data compare with positive judgements of inadequacy. The question implied by this approach is whether or not a judgement of inadequacy can be physically measured with any certainty.

Following this plan of comparison, the next step is to determine the proportion of each room type that is judged by the tenant to be inadequately lit:

ROOM TYPE	PERCENTAGE JUDGED INADEQUATELY LIT
kitchens	48
living rooms	28
bedrooms	24
TOTAL	100 per cent

By dividing these inadequately lit rooms by an arbitrary scale of daylight factor it is possible to obtain the proportion, by room type, of the inadequately lit rooms lying above a given level in terms of Waldram analysis and light meter readings. The most convenient scale of daylight factor levels is that of the British scale already used for previous comparison, that is, 0.5 per cent, 1.0 per cent and 2.0 per cent. The results of this step are as follows:

	KITCHENS		LIVING ROOMS		BEDROOMS	
	Meter Diagram	Waldram Reading	Meter Diagram	Waldram Reading	Meter Diagram	Waldram Reading
Rooms above 2.0% D.F.	27	14	45	36	33	nil
Rooms above 1.0% D.F.	32	23	64	36	33	nil
Rooms above 0.5% D.F.	32	45	82	64	33	100

The conclusions that may be drawn from the analysis cannot be considered well founded unless a larger sample analysis shows similar trends. Nevertheless, the procedure is instructive and the data do at least show a trend within the limits of the analysis.

First, the consistently higher Waldram diagram figures indicate the effect on the light meter readings of window coverings.

Second, it would seem that a very significant proportion of rooms judged inadequately lit enjoy 2.0 per cent or more daylight factor. If a similar trend could be shown in a larger sample analysis it could mean that an acceptable standard for daylighting would be in a range above 2.0 per cent daylight factor, which is substantially higher than the range of levels of the British standard.

Third, in a very general way Waldram diagram data and light meter data appear to be mutually supported. In theory, the two methods of measurement should yield very close results, but the great variety of window coverings would never allow this to be the case in reality.

Finally, it appears that daylight in living rooms is more important than in kitchens. This possibility was solidly indicated by answers to question 7 of the schedule. Bedrooms remain the least important. According to the British standard, kitchens ought to have the highest standard. The reason for the difference in this sample might be explained first, by the small size of apartment kitchens in the test area; in general they afford only enough room to work and are not sitting rooms or dining areas. Second, the equipment is semi- or fully-automatic, so that the time of preparation would be less than if the equipment were manually operated throughout; moreover, the kitchen equipment is well equipped with artificial light.

SUMMARY AND CONCLUSION

The main objective of the study was to evaluate the relationship between daylight in the space between buildings and light within the buildings. A second objective was to evaluate the methods of measurement selected. To accomplish both objectives an existing site was studied. Underlying the whole study and the program for site investigation was a realization that the measurement program must yield not only physical measurements of daylighting conditions but also information regarding the importance of the physical measurements.

In general, the study does succeed in its broad objectives. But success is qualified. The main reason for this is the limited area of the field investigation. The sample of tenants is too small to yield the kind of data from which conclusions may be drawn with certainty. Nevertheless, the problems encountered and the limitations they impose on the results are in themselves instructive.

A LARGER STUDY IS INDICATED

The most important conclusion that can be drawn from this field project is that a larger study is required. Given a larger, more representative sample, the trends indicated by the present data could be checked to determine whether or not they represent real conditions. The finding that a very significant proportion of rooms have poor daylighting is in itself enough justification for more widespread and detailed investigation. Determining the size of the study required is a problem; presumably it would depend on the purpose of the survey and the degree of confidence required of the results. It would also depend on the complexity of the survey technique and the variety of conditions to be investigated. For example, in Britain the sample sizes for daylighting survey work have included more than 2000 households for one program.

PERFORMANCE AS A BASIS FOR MEASUREMENT

In spite of the limited size of this study the procedure and results confirm the direct and useful quality of the performance approach in assessing the adequacy of outdoor space in providing for daylighting conditions indoors. Although the trends derived from the sample are rough and only partly confirmed, they are sufficient to point out the inadequacy of the kind of standards and regulations for open space and siting that determined the form of the test area. The daylighting effects of the three kinds of open space considered (sideyard, road, lane) are large and nowhere can evidence be found that the original specification standards used to site the buildings of the test area achieve at least an acceptable minimum uniform condition of daylighting. In fact, the only space standard employed as such is an arbitrary specification of sideyard width, the street and lane spaces being derived from considerations having nothing to do with daylighting or even with the siting of buildings. The fact that the specification standard governing street and lane spaces in the test area results in average to good daylighting conditions within the buildings is quite accidental. Opposed to this lack of a clear rationale and objective of the specification standard is the performance approach demonstrated in the measurement program of the study. Any daylighting standard for open space, or for that matter any open space standard, must be clearly related in form and application to the specific desired objectives for conditions that will result indoors.

A COMPREHENSIVE APPROACH NECESSARY FOR VALUING

The problem of valuing is the principal complication in setting any planning standard for open space or the siting of buildings. Setting objectives for space standards is possibly the easiest problem. Determining methods of measurement so that environmental conditions may be physically assessed or quantified is harder to resolve. But finding some concensus regarding the importance of the measurements is doubtless the most difficult problem of all. This study concludes that no single criteria exists for the valuing of a daylighting standard. To accomplish the job of valuing it is necessary to take into account a variety of evidence to find where the concensus lies so that the standard is acceptable to the community. Because this is necessary a comprehensive approach is required. Accordingly the program for the field study included analysis, field measurement and the subjective judgements of the interviewer and the tenant. While the authors are understandably cautious in making claims on the basis of the test sample, the overall trends indicated by each approach are mutually supported. In general, areas where low daylight factors were calculated or measured were judged by the tenants and the interviewer to be unsatisfactory areas. Moreover, the daylighting effect of each of the three classes of outdoor space (sideyard, road, lane) was found to be of the same kind, whether assessed by analysis, field measurement, or the judgements of tenants and the interviewer. The problem, however, of comparing the three approaches so that judgements may, in effect, be measured requires a sample containing a sufficient number of dwellings that have been analysed, measured by light meter and judged by the tenant and interviewer. The degree of confidence in any standard derived from the combined data clearly depends on how representative the sample is of the whole housing group under consideration. The correct size of sample is therefore of basic importance.

Bearing this in mind an attempt was made to "measure" the judgements of tenants to establish what standard of daylighting would be acceptable on the basis of the 36-room sample derived from the interview program. The result of the analysis indicates that the standard would exceed 2 per cent daylight factor and that living rooms would be as important in terms of daylighting as kitchens. Bedrooms would have the least daylighting importance.

In general the study does confirm that the value of daylighting depends on more than functional seeing criteria. It is strongly indicated that valuing must include some consideration of such factors as view, orientation, and isolation. It would seem that the experience of daylight is ecological in nature.

SURVEY TECHNIQUES REQUIRE REFINEMENT

The field study began with the possibility of gathering full data records for a total of 396 rooms. This total was achieved for the Waldram analysis record because nothing more than the plans of the buildings was required. The light meter record includes 120 rooms rather than 396, because it was necessary to get permission to enter apartments when the sky was sufficiently overcast. The tenant judgement record includes 149 rooms rather than 396, again because it was necessary to get permission to enter apartments. Complete records could be obtained for only 36 rooms. There is no doubt that the main factor affecting this total was the weather. When an appointment was made with a tenant it was largely a matter of luck whether or not the sky would be correctly overcast when the meeting took place. If the weather was not correct at the time of the appointment a decision had to be made whether to go ahead and gather partial records or to try for another appointment with no better guarantee of success.

An additional complication imposed by the weather was the problem of attempting to gather judgements of daylighting adequacy when the sky was not correctly overcast for meter readings because the standard overcast sky represents a good and common minimum condition. Under any other circumstances the tenant would have to rely on recall. Moreover, judgements gathered under different weather conditions cannot be considered strictly comparable. To achieve a better sample it is therefore important to resolve this problem.

On the basis of the present experience two steps are clearly indicated. First, more effort and better techniques must be invested in winning the initial cooperation of tenants through the use of good endorsement, more personalized mailing material and telephone contact. Second, more staff is required in order to capitalize on good weather conditions.

CONFLICTS

The study found that tenants place a high value on visual privacy. To obtain it, however, many found it necessary to close off their windows, as they could be overlooked from apartments as little as 10 and 12 feet away. In some cases the tenants themselves objected to being overlooked; in others they feared that nearby tenants would feel that they were being overlooked. The effect of closing blinds on windows, particularly in sideyard spaces, was often a reduction of from 50 to 75 per cent illumination.

THE PERFORMANCE OF OPEN SPACE

The study found that the spaces of the streets and lanes surrounding the test area buildings performed well in providing an acceptable level of daylighting indoors. In fact, there is some indication that the scale and form of the street space in relation to the test area buildings is more than necessary as far as daylighting is concerned. But there can be no doubt that for the conditions represented by the study area the traditional sideyard space or the kind of space equivalent to it is a major source of daylighting trouble and of other trouble such as lack of visual privacy. This trouble has a definite effect on daylighting, on the standard of living indoors and on the whole quality of the housing and the morale of the people therein. While a condition as severe as this appears obvious wherever it exists, it is nevertheless vital that the condition be properly measured and evaluated. It is in this area that the field study gathered the clearest and fullest tenant reaction and cooperation.

FOOTNOTES AND REFERENCES:

1. There are two outstanding reasons why the survey method offers a "broad and sturdy basis." First, the method works well in gathering subjective and objective criteria and as a result has functional merit. Second, the method respects the political content that certainly exists in setting development standards. However, it is instructive to note how seldome any judgement sampling is thus employed, except of course in Britain. See for example, City of Vancouver Technical Planning Board, <u>City of Vancouver, Report On Proposed Revisions to Apartment Zoning Regulations</u>, Report No. 2, 1960, p. 14, which invited the local architects and Board of Trade to suggest changes needed to improve the amenity of apartment development. The

architects were asked because they would have to work with the revisions; no information was gathered from those who would have to live with them. For many reasons to support the survey method see for example, Jackson, Dr. J.N., Surveys for Town and Country Planning, Hutchinson University Library, London, 1963.

2. See for example, "The Lighting of Buildings," Report No. 12, (H.M.S.O., 1944) Appendix V, VI; Gray, P.G. and Groslett, T. "A Survey of Lighting in Offices," Report No. 30, (H.M.S.O., 1952), Appendix I.

3. The final choice of a building for study really depended on the cooperation of the building owner and janitor. Originally, buildings 9, 10, 11 and 12 were chosen for study but the owner of building 9 refused to cooperate, giving as his reason, a fear of disturbing the tenants. Building 1 replaced 9 as a reasonably equivalent example of a corner development.

4. The consultant was the School of Social Work, University of British Columbia. Additional assistance was obtained from the Planning Department, City of Vancouver.

5. The feature of the crime wave that annoyed the study occurred when the City Police Department publicly advised tenants to be cautious with unknown persons having unfamiliar or unusual requests. The exact effect of this complication is indeterminate although it certainly contributed to the number of "refusals," particularly among retired people. In some cases where it was clear that an interview could be gained by added effort a special personal letter proved helpful.

6. Various reasons were given. The most common was that beds were unmade. Forty-two per cent of cooperating respondents refused to cooperate fully in showing all their rooms.

7. The "Lighting of Buildings" survey used classifications of income presumably because they were useful where the cost of electric light and fuel was high. This was not regarded as a consideration here because of central heating and the traditional regard for the use of electric light. However, some thought was given to the possibility that daylighting quality might be reflected in the level of rents. To a degree that was quite surprising this was not true. Evidently only two components existed in setting rents in the four study area buildings: The dwelling size, including the number of rooms, and whether the dwelling was in a basement.

8. There are several exceptions to this policy. They occur in dwellings with the least amenity, for example, the majority of households with children occupy either cheaper basement apartments or dark sideyard apartments on first floors. The majority of mothers encountered were single or divorced and worked. Their homes provided some testimony of the forces of natural selection in housing and reflected the general economic and social problems of these people.

9. See for example, "Building Illumination," The effect of New Lighting Levels, National Academy of Sciences, National Research Council, Washington, D.C., Publication 744, 1959, p. 31.

10. The Waldram diagram employed was corrected for a C.I.E. standard overcast sky according to figures amended to September 1959 and compiled by P. Petherbridge. The figures were extracted from C.I.E. Draft Guide to Natural Daylight Calculations, Part I, Overcast Sky Conditions, Tables 4, 5. The luminance of obstructions was considered to be 10 per cent of sky luminance. No internal reflected component was determined.

11. The five points were obtained in each room by dividing the two centrelines, that could be drawn normal to each other in any room, into four equal parts.

12. The park is flat, without trees and covers about half a square block. It thus afforded an opportunity to obtain substantially unobstructed meter readings of incident illumination from the whole sky. Initially such readings were contemplated from the building roofs but because of complications in opening up access this procedure was dropped in favour of the park.

13. Assistance was received in the choice and use of light meters. Three meters were tested. These included a Leeds-Northrup photometer that provided very accurate readings at low levels of illumination, a "Seconic Studio type" photo-electric meter and a "Spectra" meter with integrating head was used for the majority of readings. Mr. C. McGregor, electrical engineer, provided assistance with the use of meters and Mr. J. Breeze of the B.C. Research Council provided facilities and advice for the calibration of the photometer.

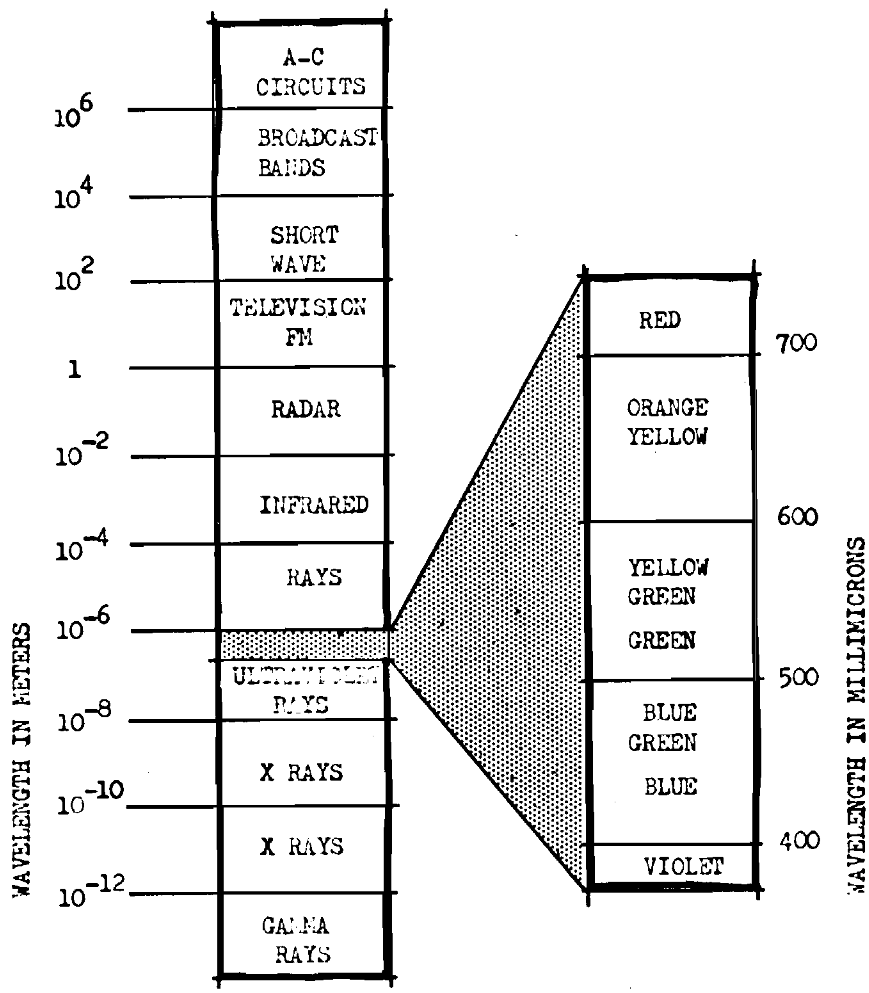


FIGURE 1

ELECTROMAGNETIC AND VISIBLE SPECTRA

BR3906-1

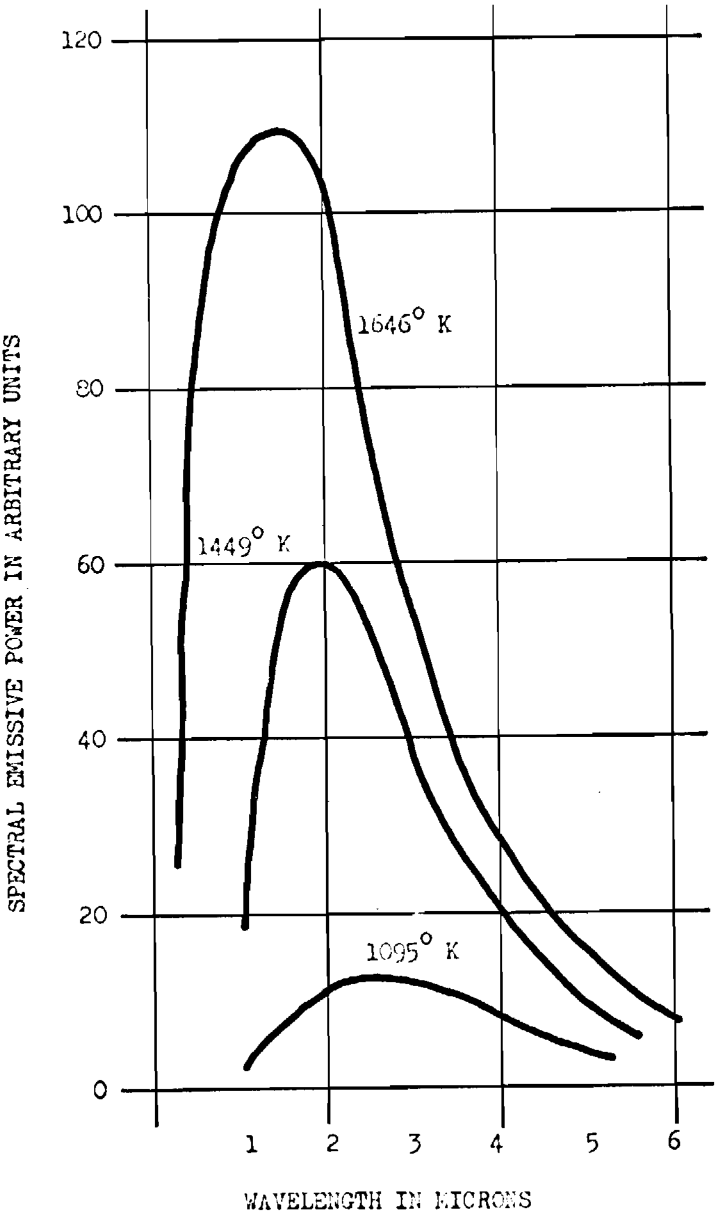


FIGURE 2

IDEAL RADIATOR OR BLACK-BODY RADIATION CURVES (Ref. 8)

BA 3906-2

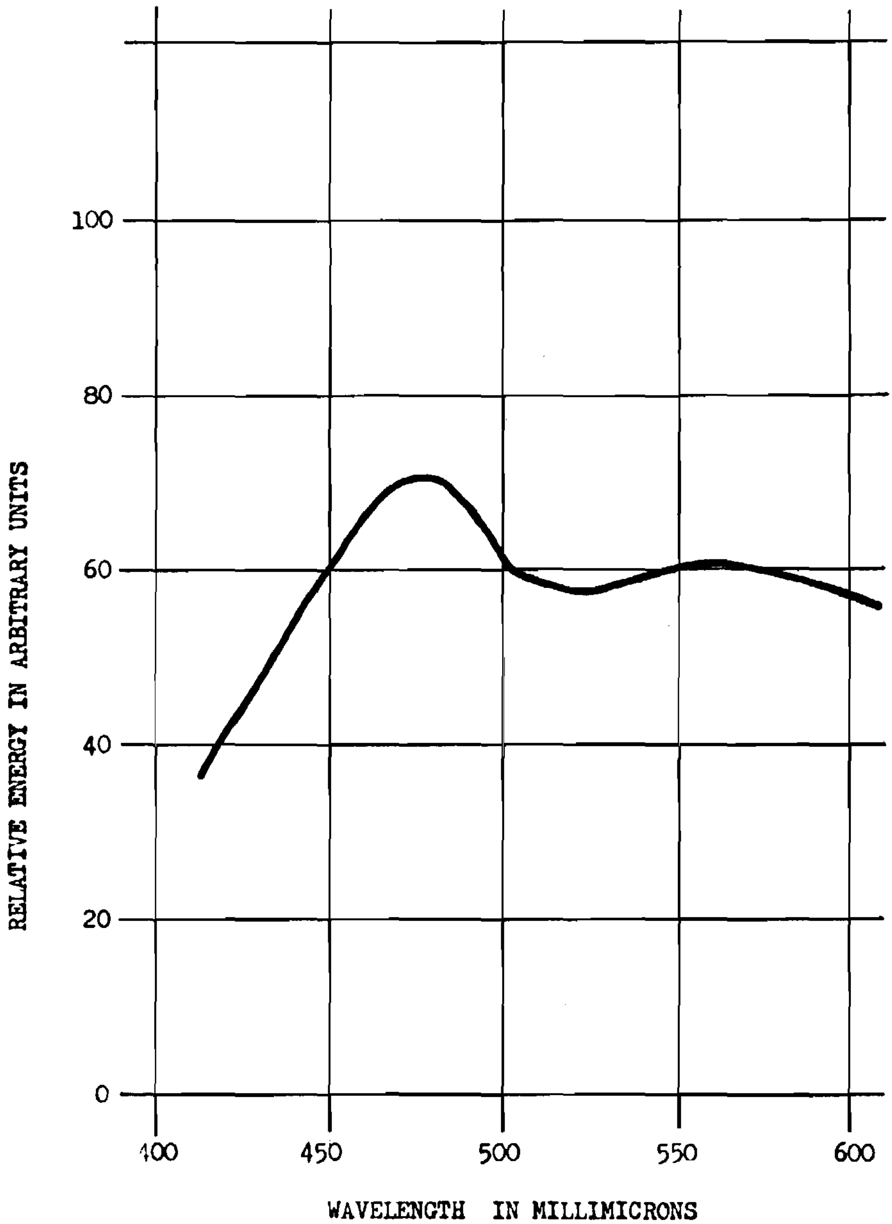


FIGURE 3

SPECTRAL DISTRIBUTION OF LIGHT FROM SUN AND CLEAR SKY WITH CLOUD COVER OF ONE-EIGHTH OR LESS (Ref. 11)

BR3906-3

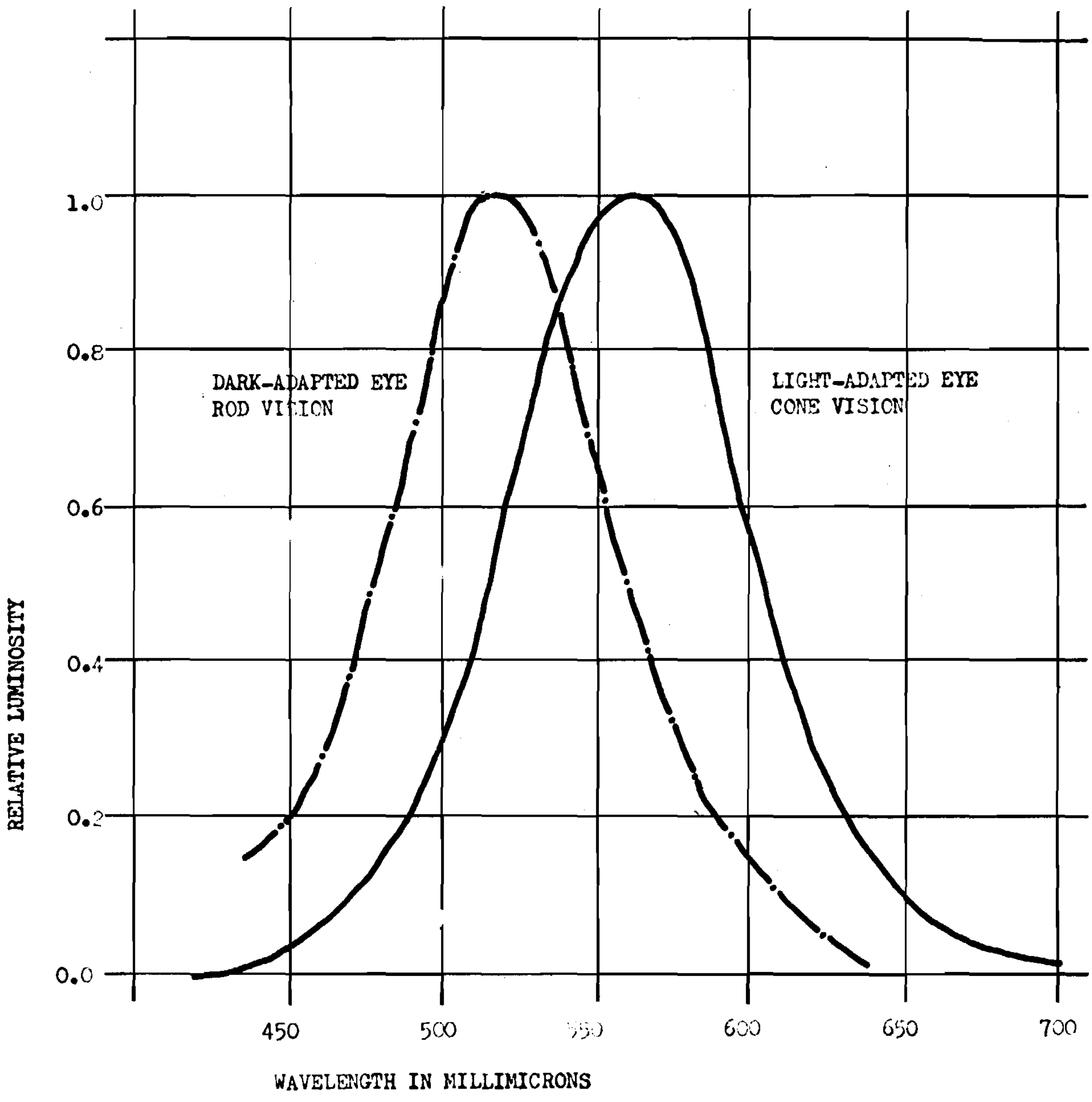


FIGURE 4

THE TWO SENSITIVITIES OF THE EYE: CONE VISION AND ROD VISION

BA 3906-4

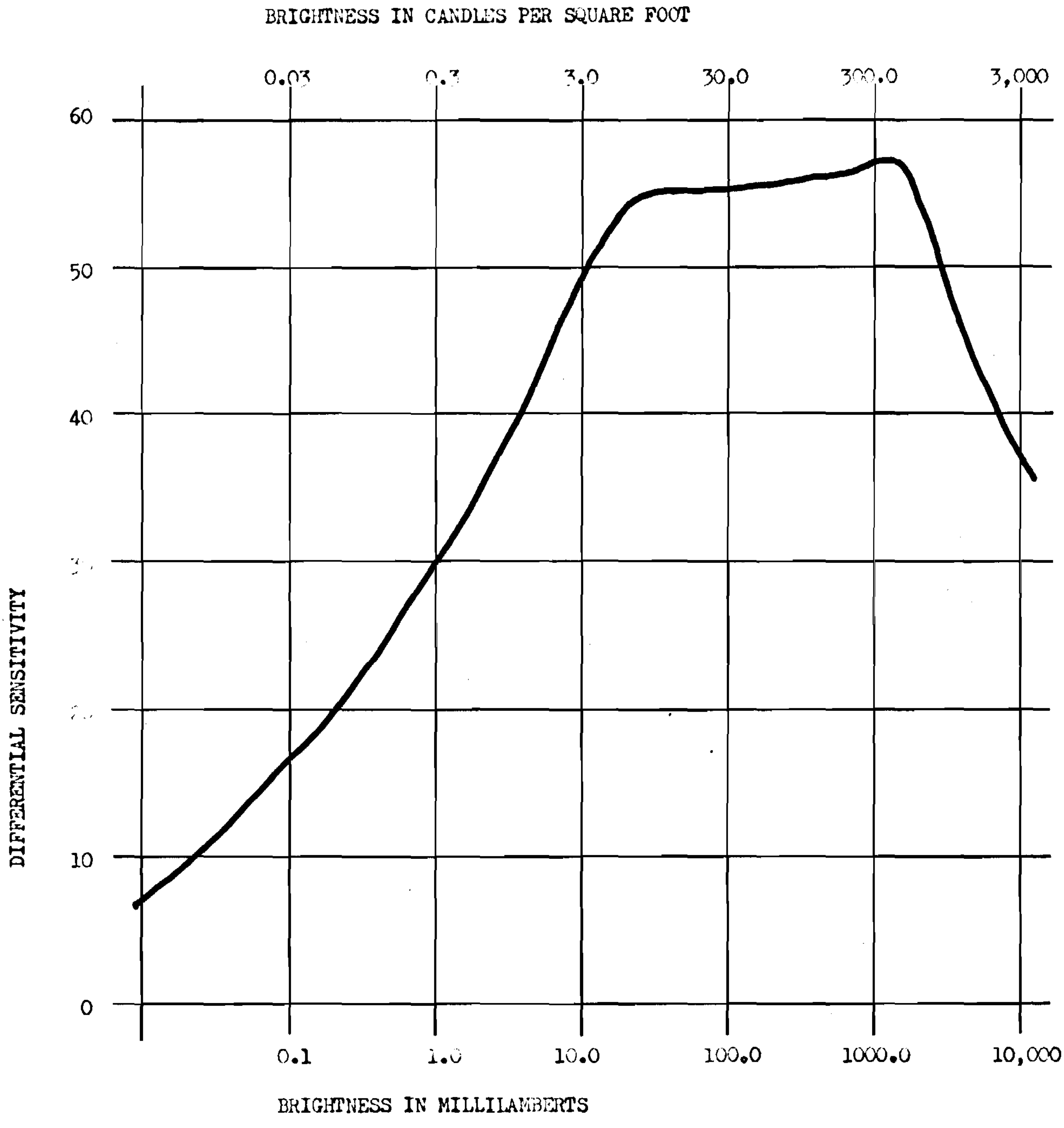


FIGURE 5

DIFFERENTIAL SENSITIVITY OF THE HUMAN EYE (Ref. 25)

BR390C-5

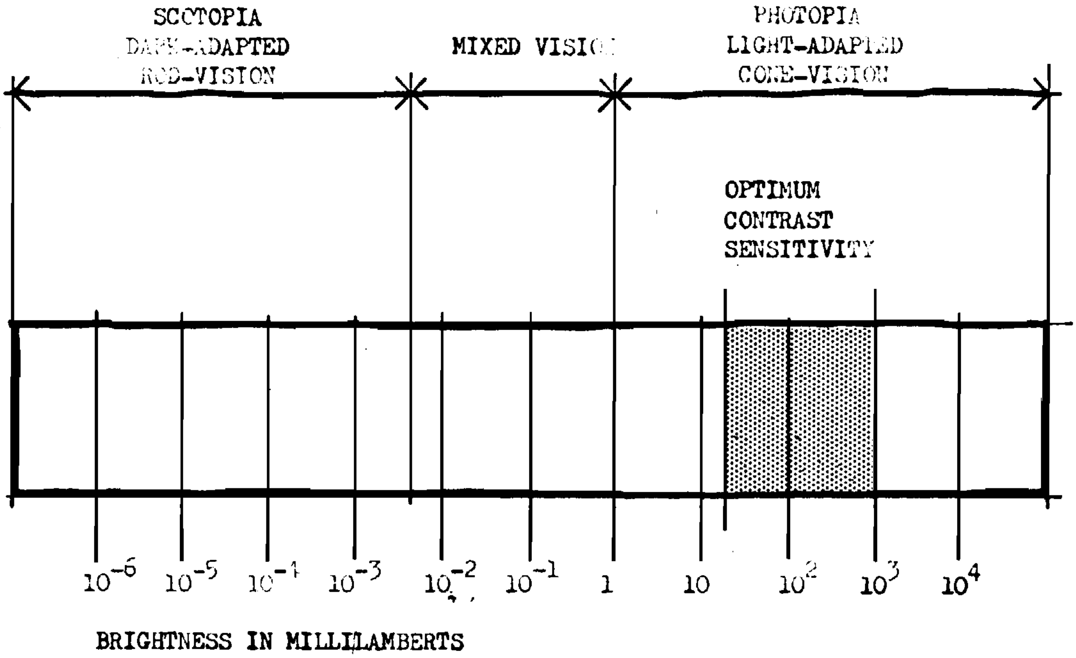


FIGURE 6

A LINEAR SCALE OF LIGHT SENSITIVITIES
(Ref. 25)

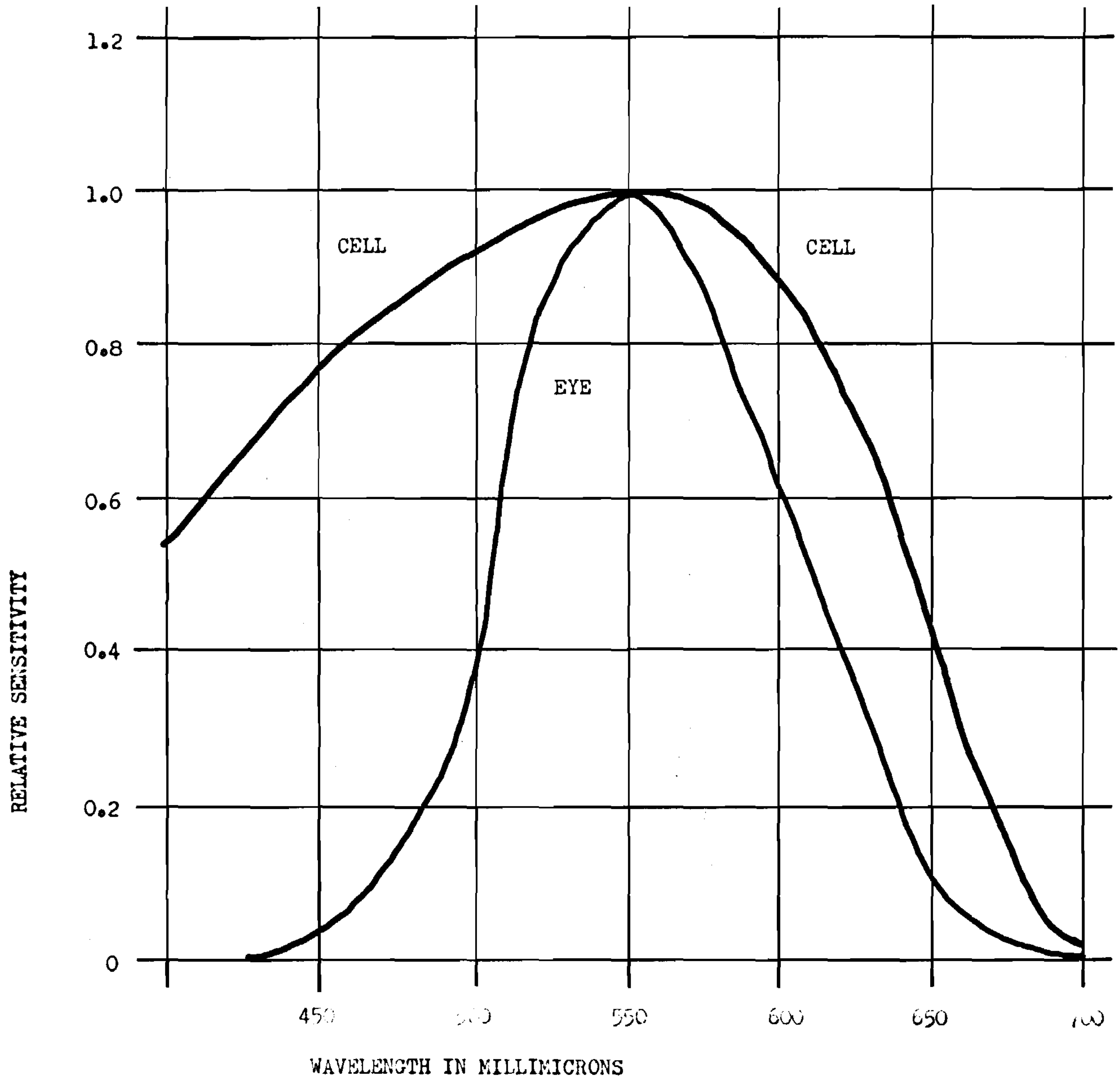


FIGURE 7

SENSITIVITY OF A PHOTO-CELL AND HUMAN EYE
(Ref. 28)

BR 3906-7

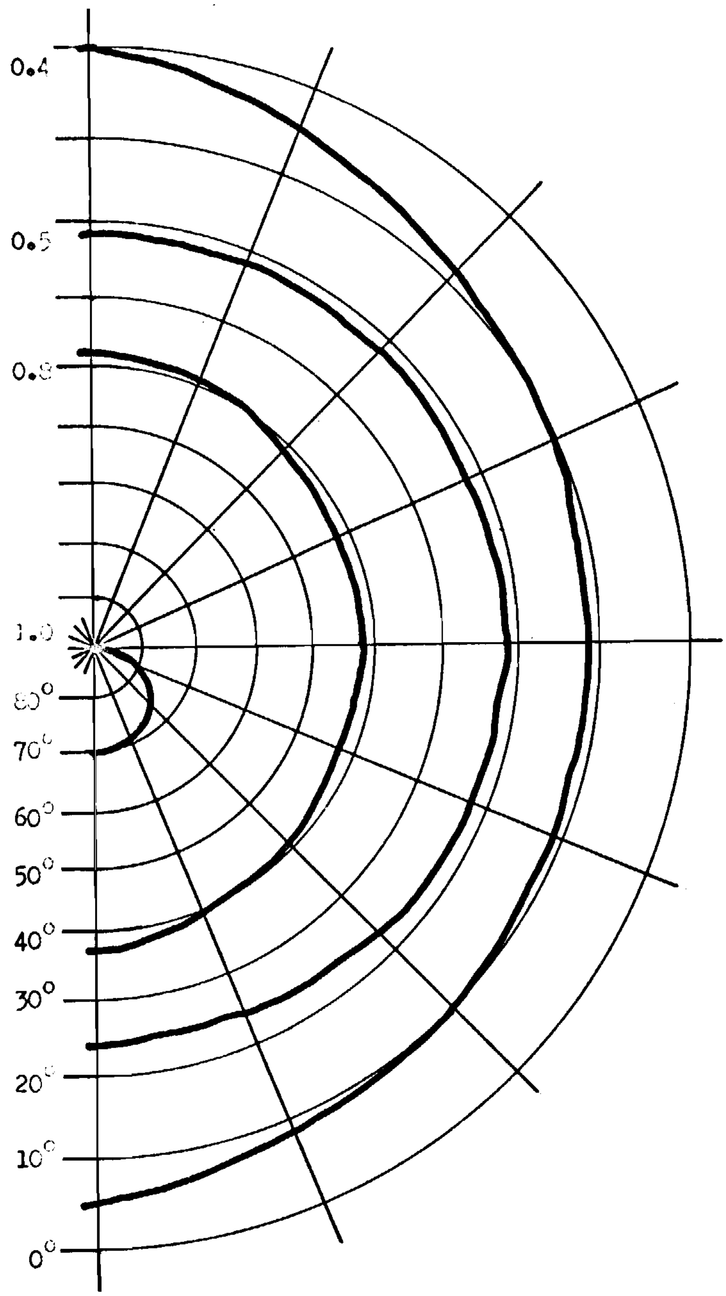


FIGURE 8

LUMINANCE DISTRIBUTION IN A DENSELY COVERED SKY FOR A SOLAR ALTITUDE OF 40 DEG. (Ref. 43)

RA-3906-B

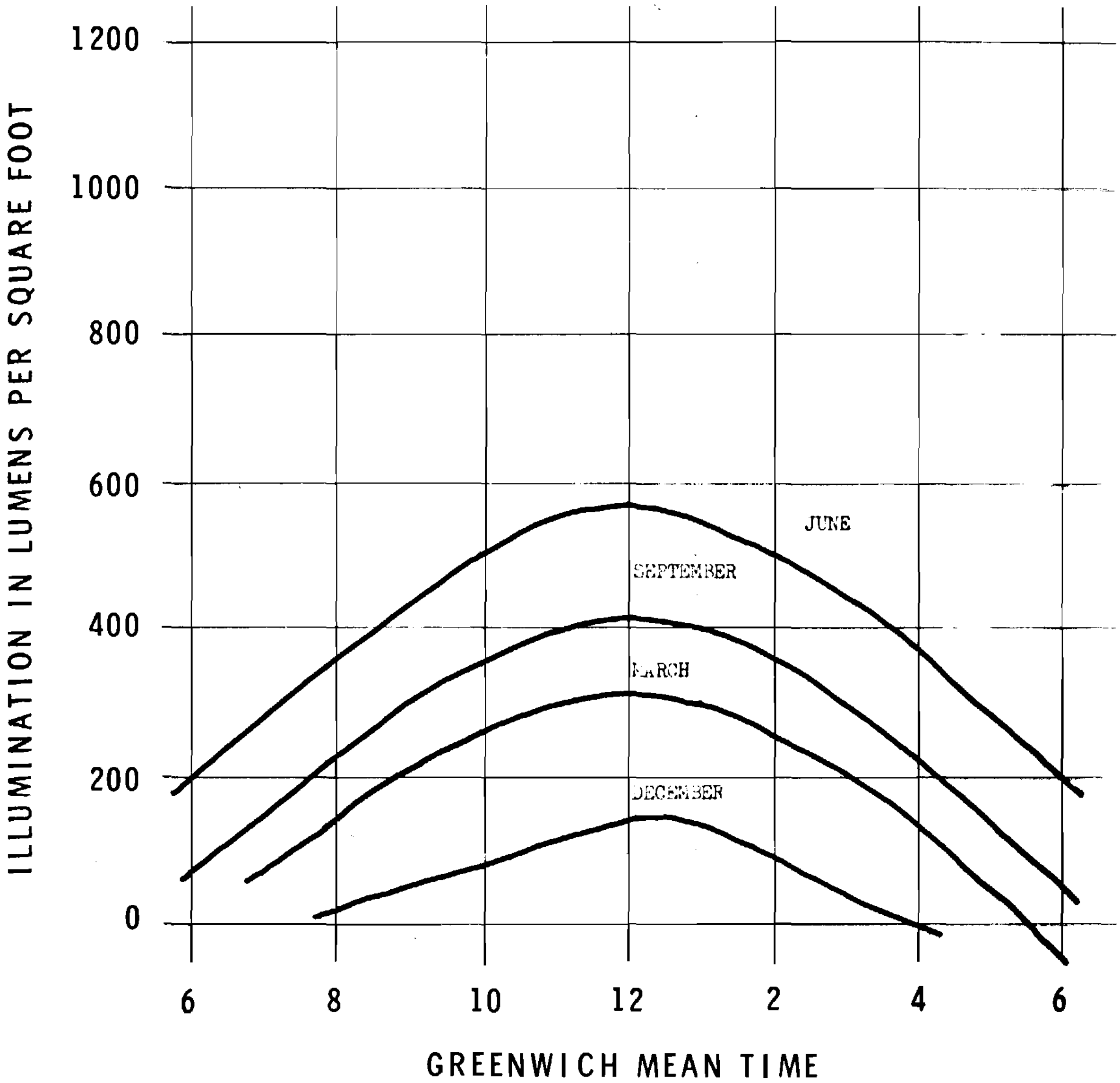


FIGURE 9

CURVES OF ILLUMINATION FROM NORTH OCTANT OF THE SKY (Ref. 44)

8A-3906-9(a)

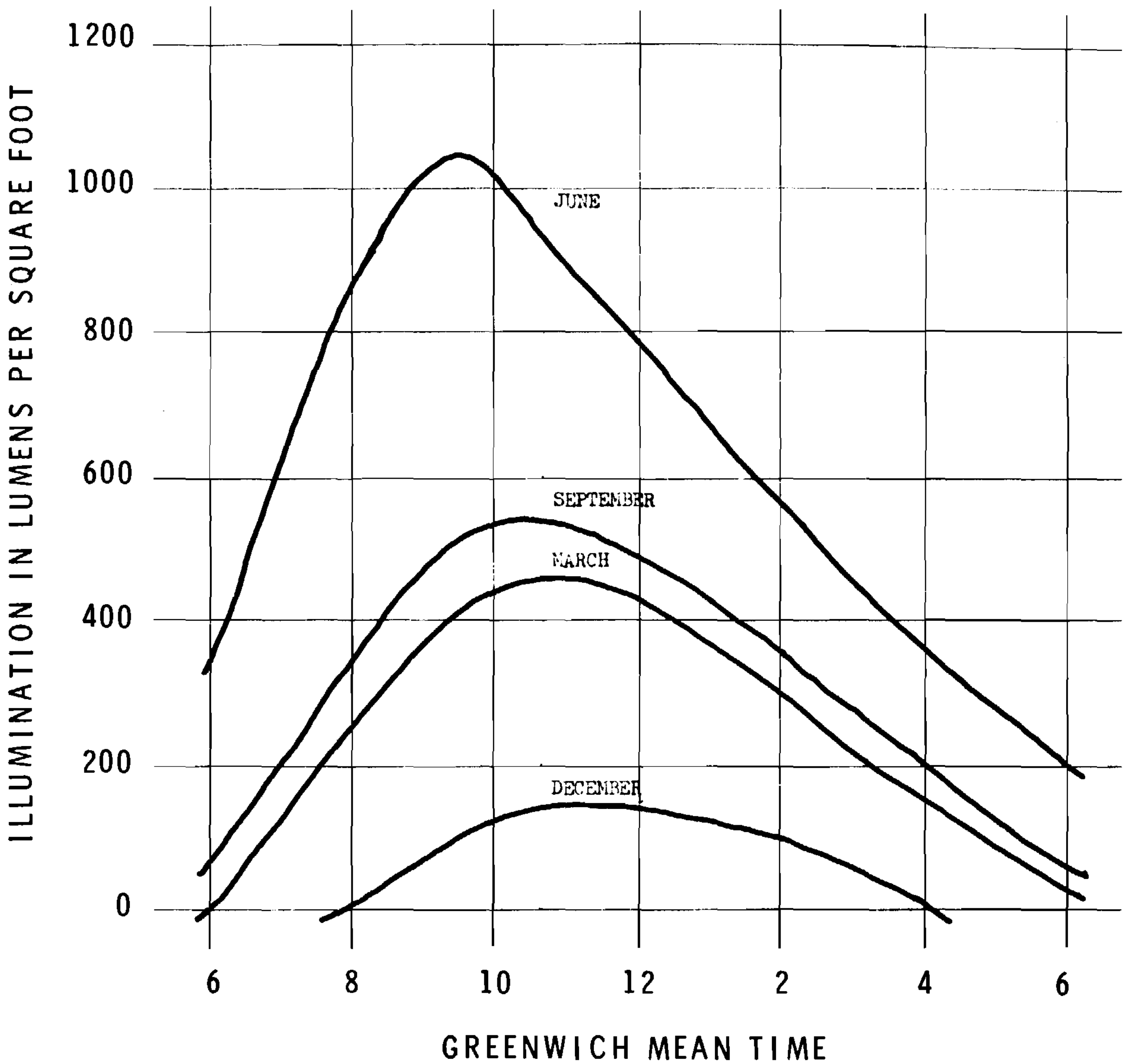


FIGURE 10

CURVES OF ILLUMINATION FROM EAST OCTANT OF THE SKY (Ref. 44)

BB 3906-9(L)

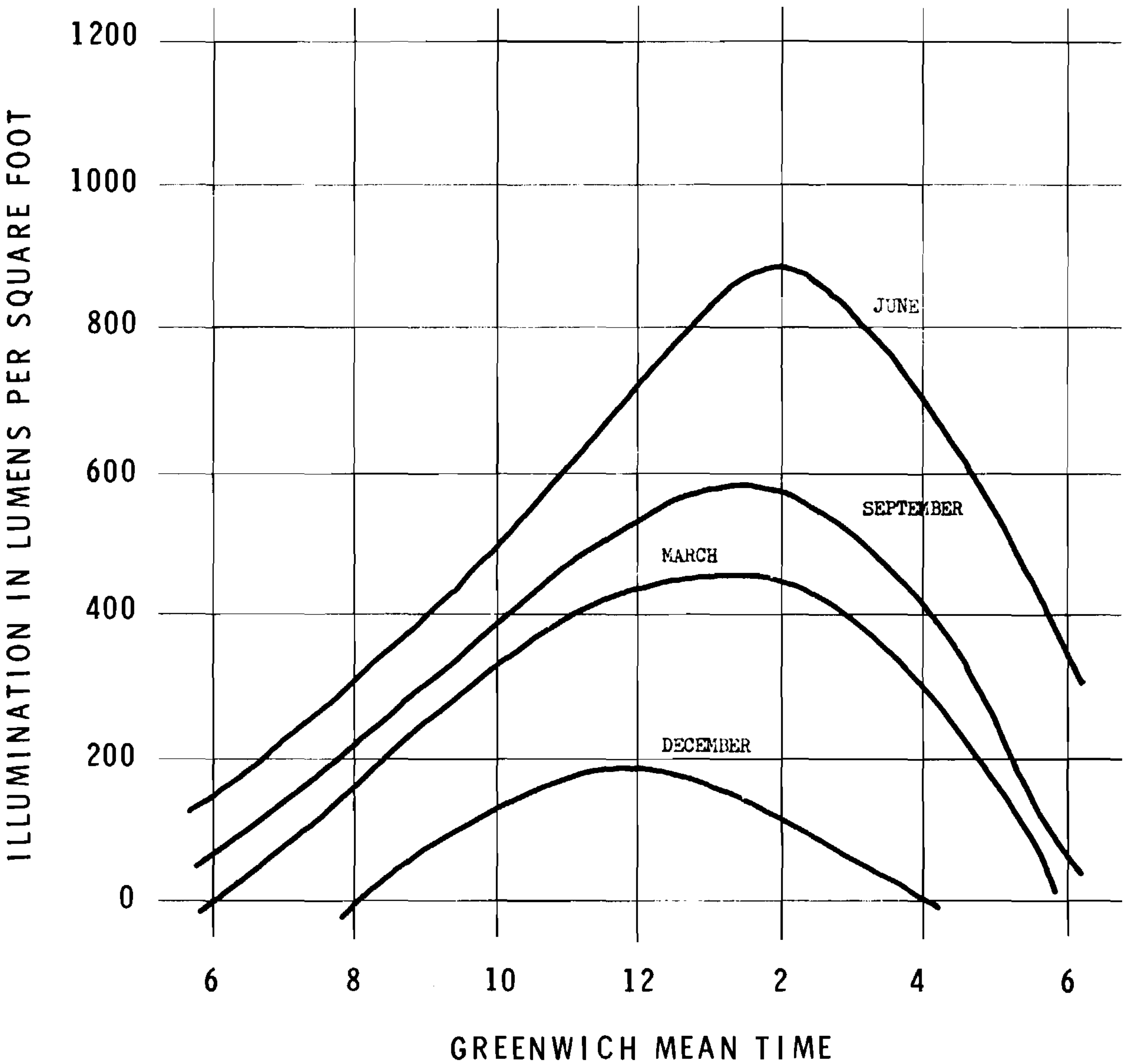


FIGURE 11

CURVES OF ILLUMINATION FROM WEST OCTANT OF THE SKY (Ref. 44)

BR 3906-9 (C)

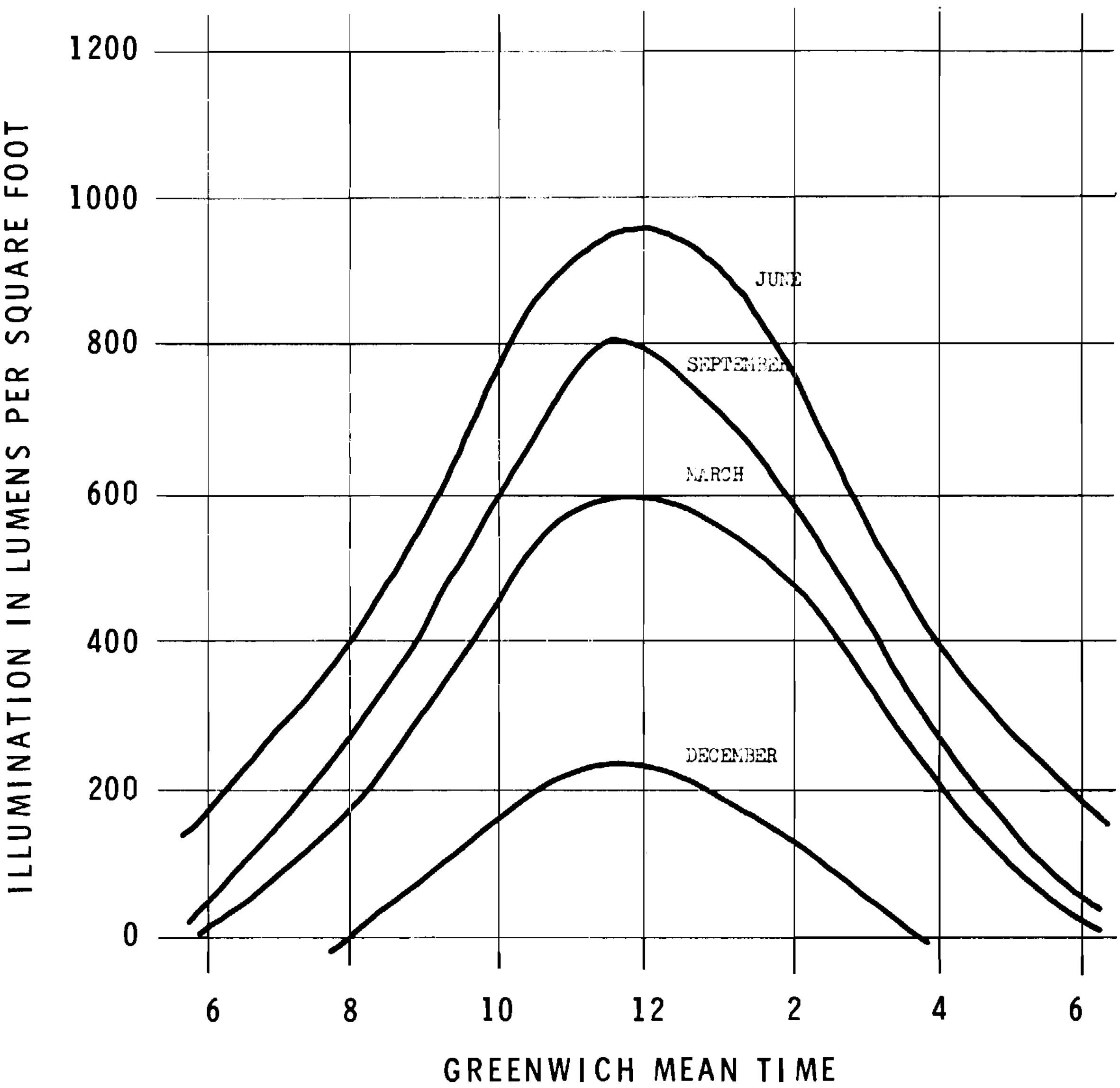


FIGURE 12

CURVES OF ILLUMINATION FROM SOUTH OCTANT OF THE SKY (Ref. 44)

BA 3906-9 (d)

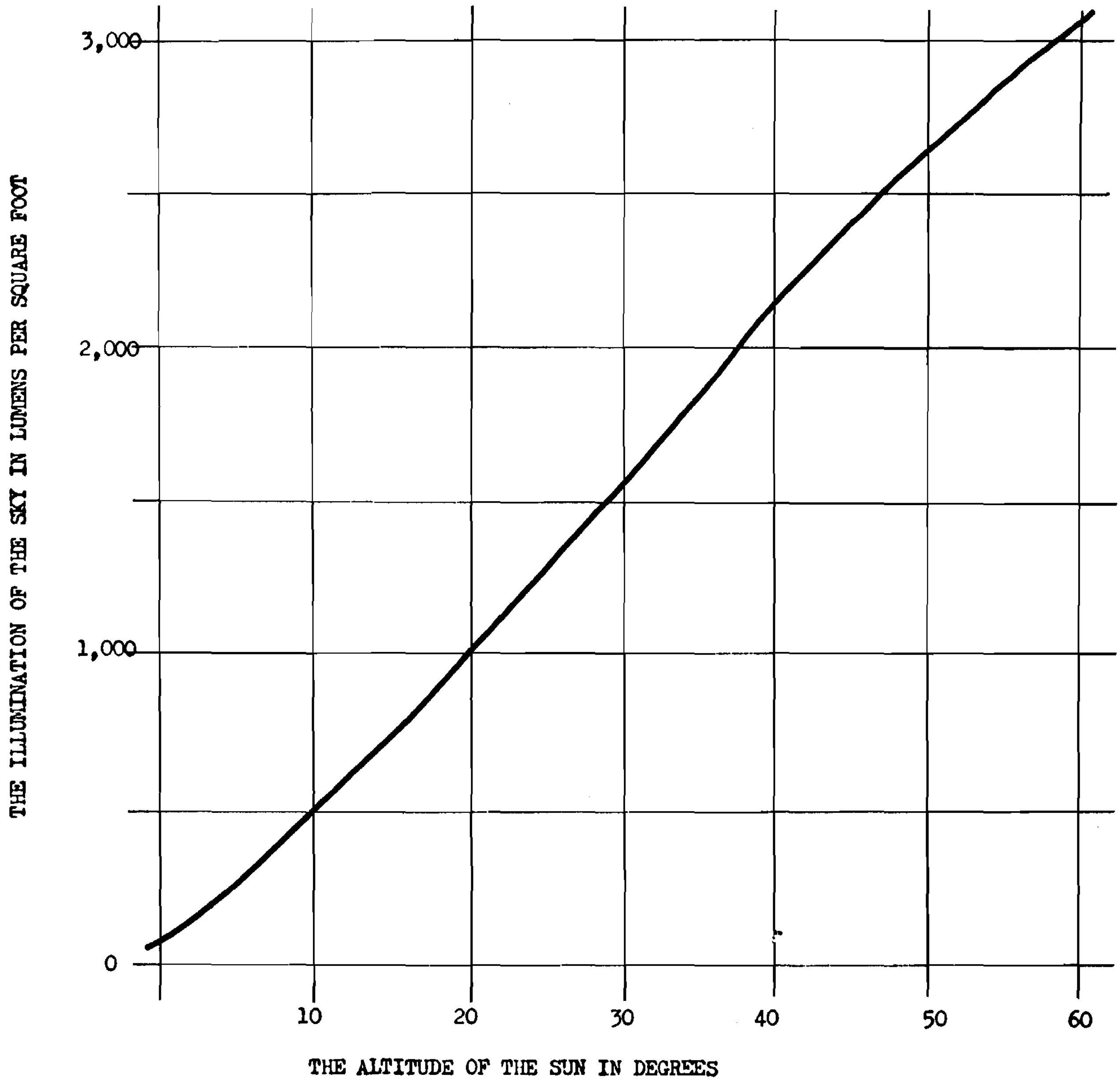


FIGURE 13

THE SUN'S ALTITUDE AND THE ILLUMINATION FROM THE WHOLE SKY (Ref. 45)

BR 3906-10

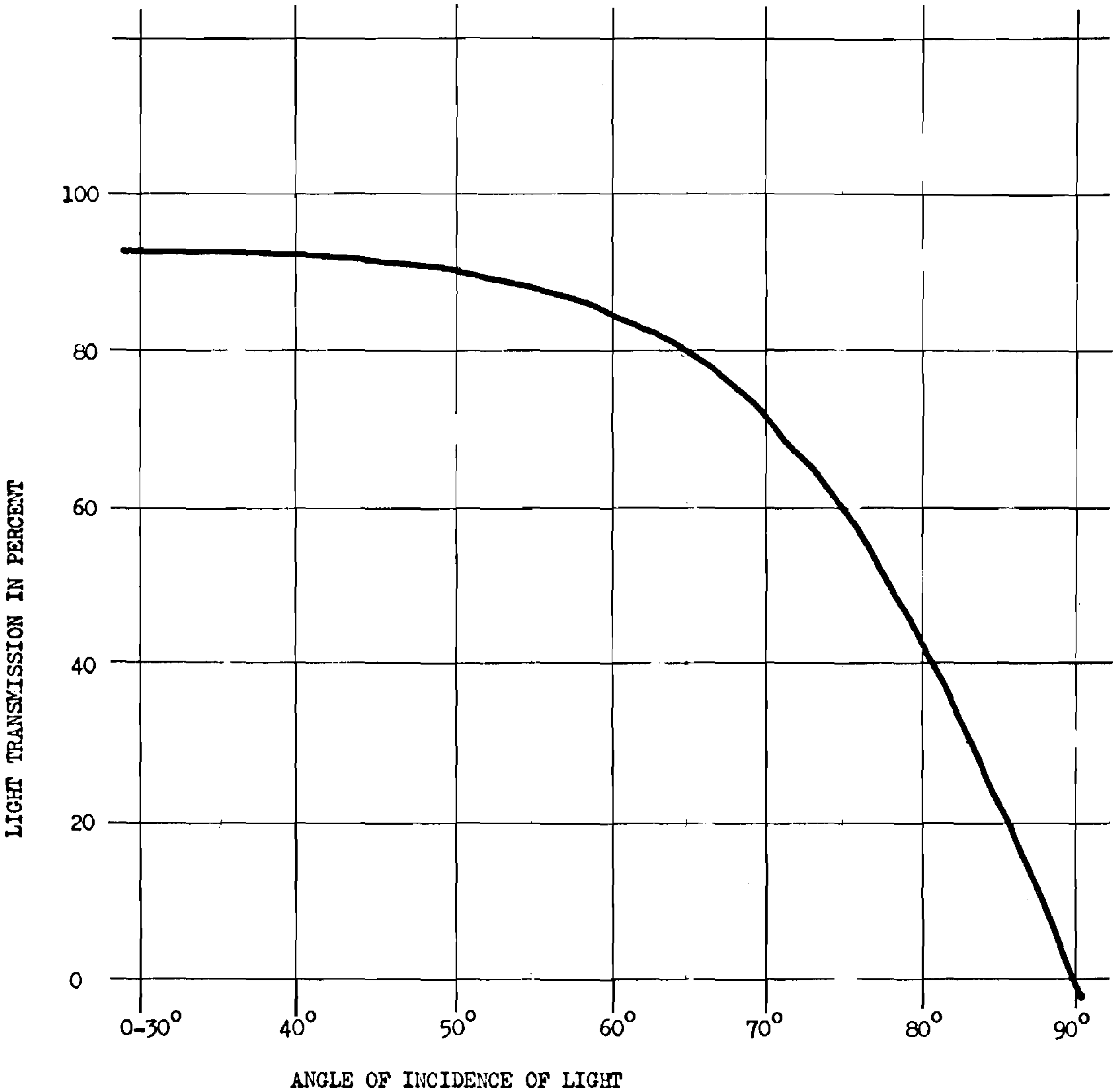
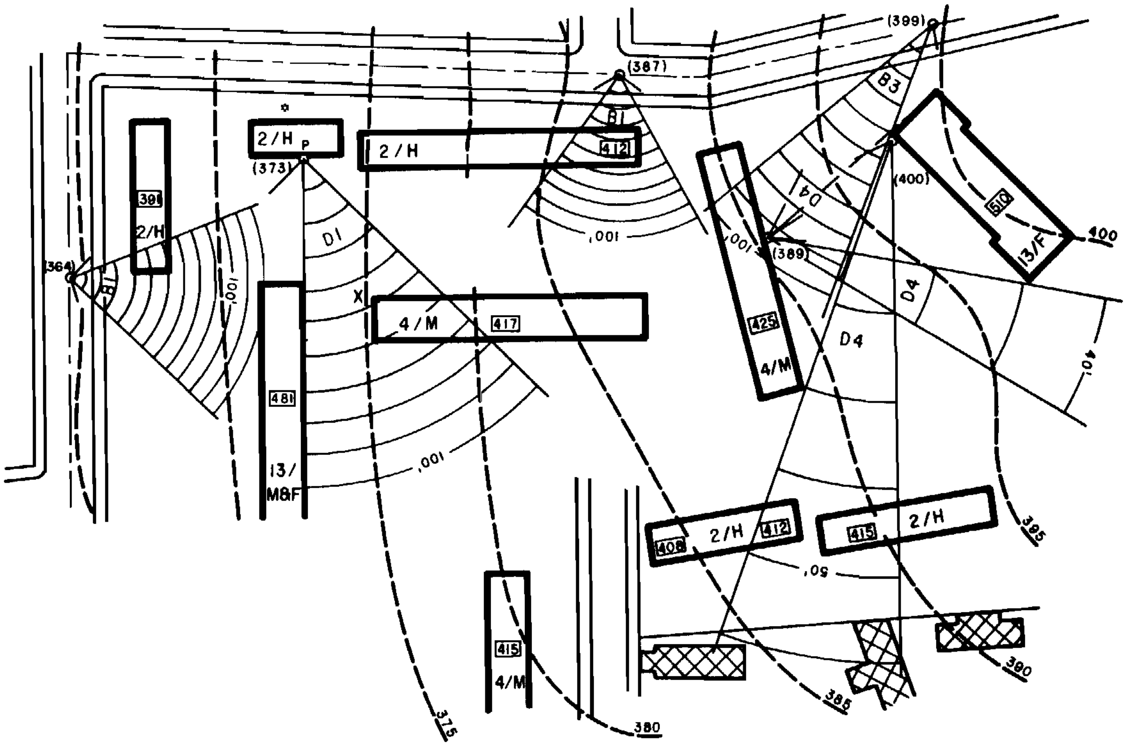


FIGURE 14

TRANSMISSION OF GLASS FOR LIGHT INCIDENT OBLIQUELY (Ref. 7)

BR 390 L-11



(a) Ground level - at a street centreline or average for the site of a particular building, shown thus....................(373)

(b) Assumed heights of roof ridge or parapet levels of different types of buildings above average ground level of the site of the building................................ 2/M...... 24 ft
4/m...... 36 ft
13/m or F 110 ft

(c) Roof ridge or parapet levels of particular buildings, = [(a) + (b)], shown thus......... [481]

* Example

Height of building at x above point P being tested = [417] - (373) = 44 feet, which is below the permissible height of 47 feet given by the indicator D1

FIGURE 15

PLAN SHOWING THE APPLICATION OF THE DAYLIGHT INDICATORS.

(For further detailed information concerning the design and application of the indicators see Reference 30.)

BR 3906-12

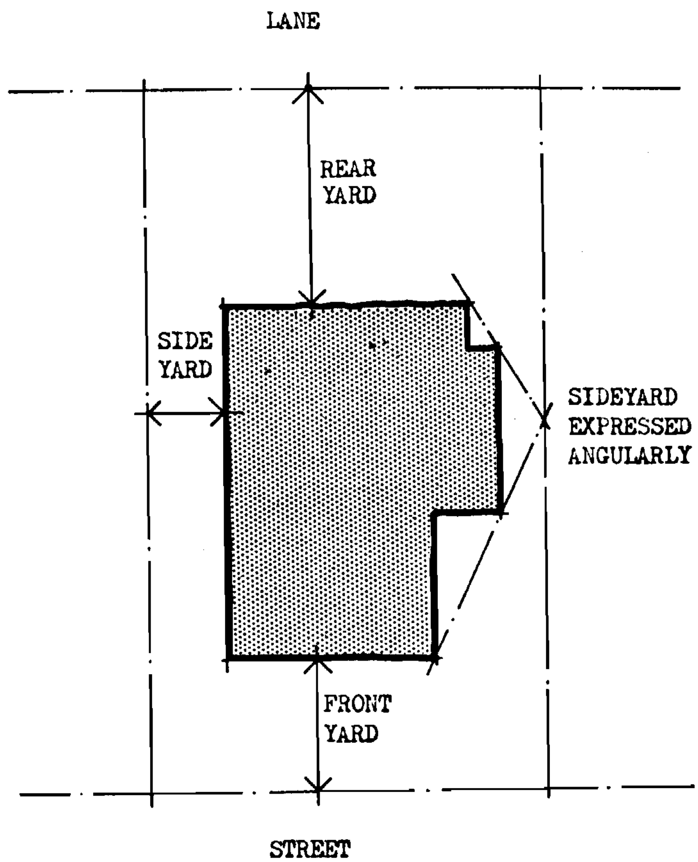
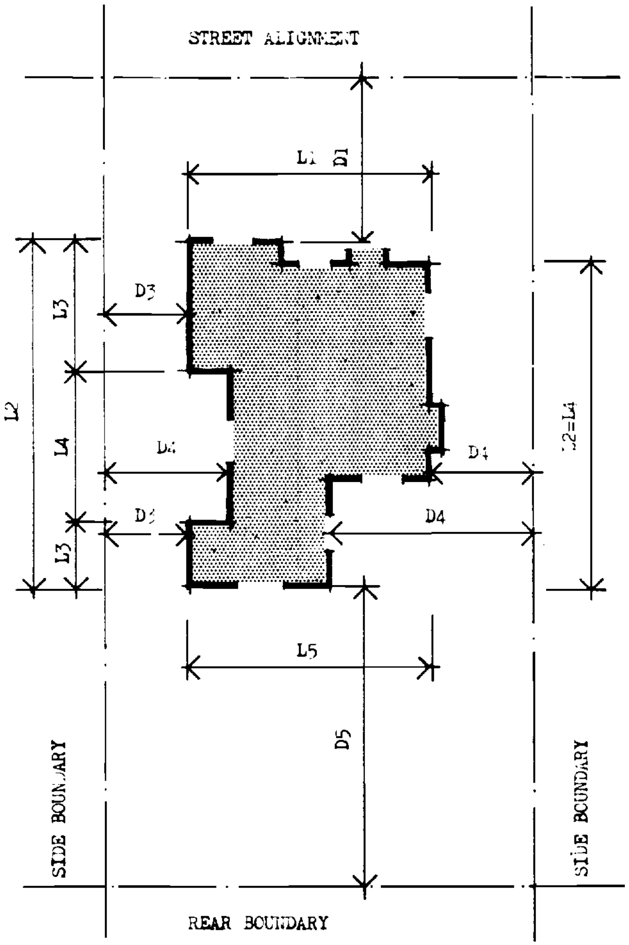


FIGURE 16

COMMONLY EXPRESSED YARD AND SET-BACK REQUIREMENTS

BR 3906-13



LEGEND

L1 is the total length of the front wall of the building and is measured as if the front wall were continuous in one plane, irrespective of any projections or set-backs.

D1 is the distance between the front wall and the street alignment, measured from the nearest portion of the wall.

L2 is the total length of the side wall, measured from the point of junction with the front wall as if it were continuous in one plane irrespective of any projections or set-backs.

L3 is the total length of side wall without windows to habitable rooms, forming part of L2.

D3 is the distance between L3 and the side boundary.

L4 is the total length of side wall with windows to habitable rooms, forming part of L2.

D4 is the distance between L4 and the side boundary.

L5 is the total length of rear wall, measured from its junction with the side wall, as for L2.

D5 is the distance between the rear wall and rear boundary.

FIGURE 17

YARD AND SET-BACK REQUIREMENTS PARTICULARIZED AND GRADUATED (Ref. 35)

BR3906-14(a)

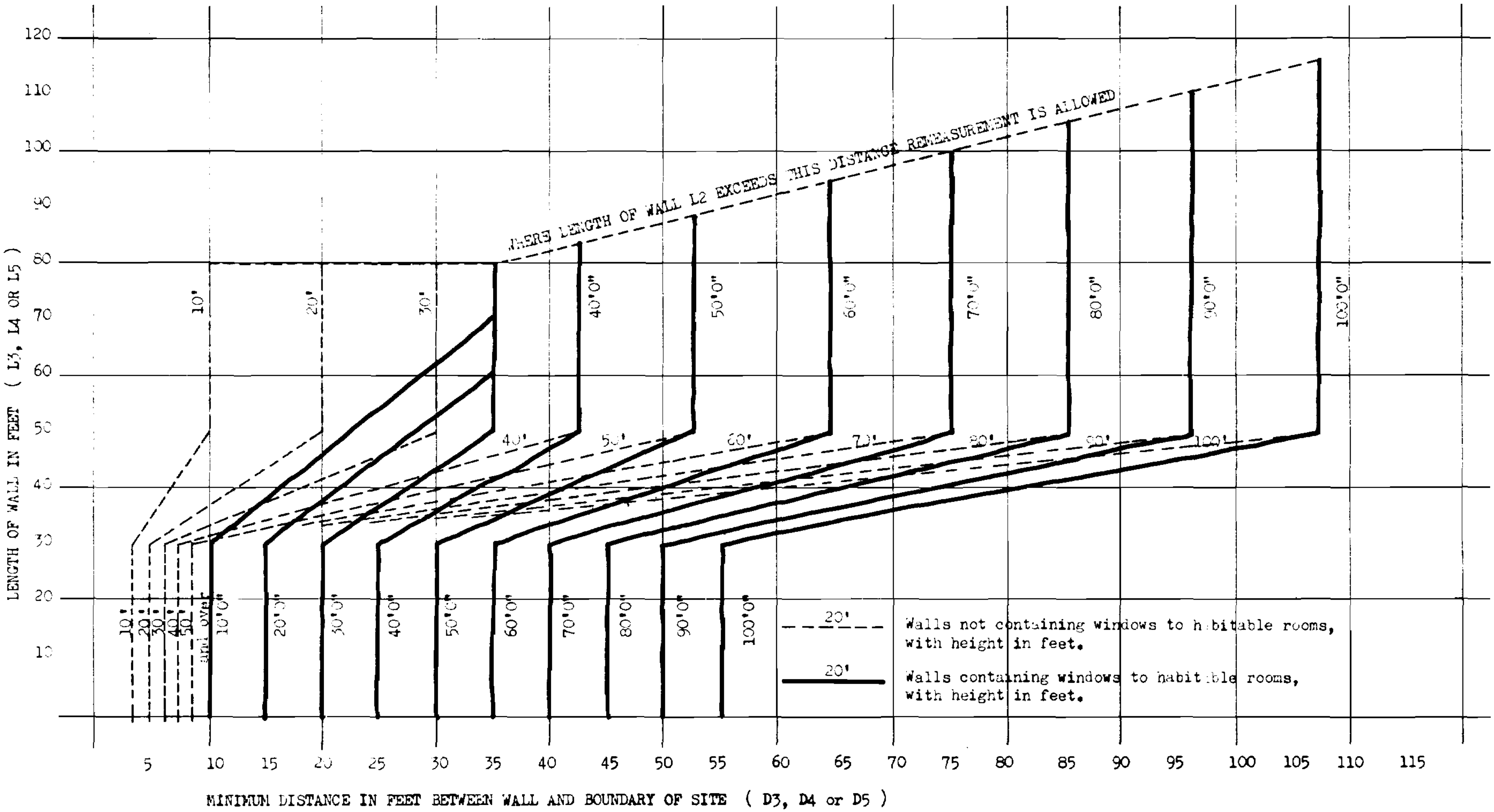


FIGURE 18

YARD AND SET-BACK REQUIREMENTS PARTICULARIZED AND GRADUATED (Ref. 35)
(See Legend, Figure 17)

BR 390C-14(b)

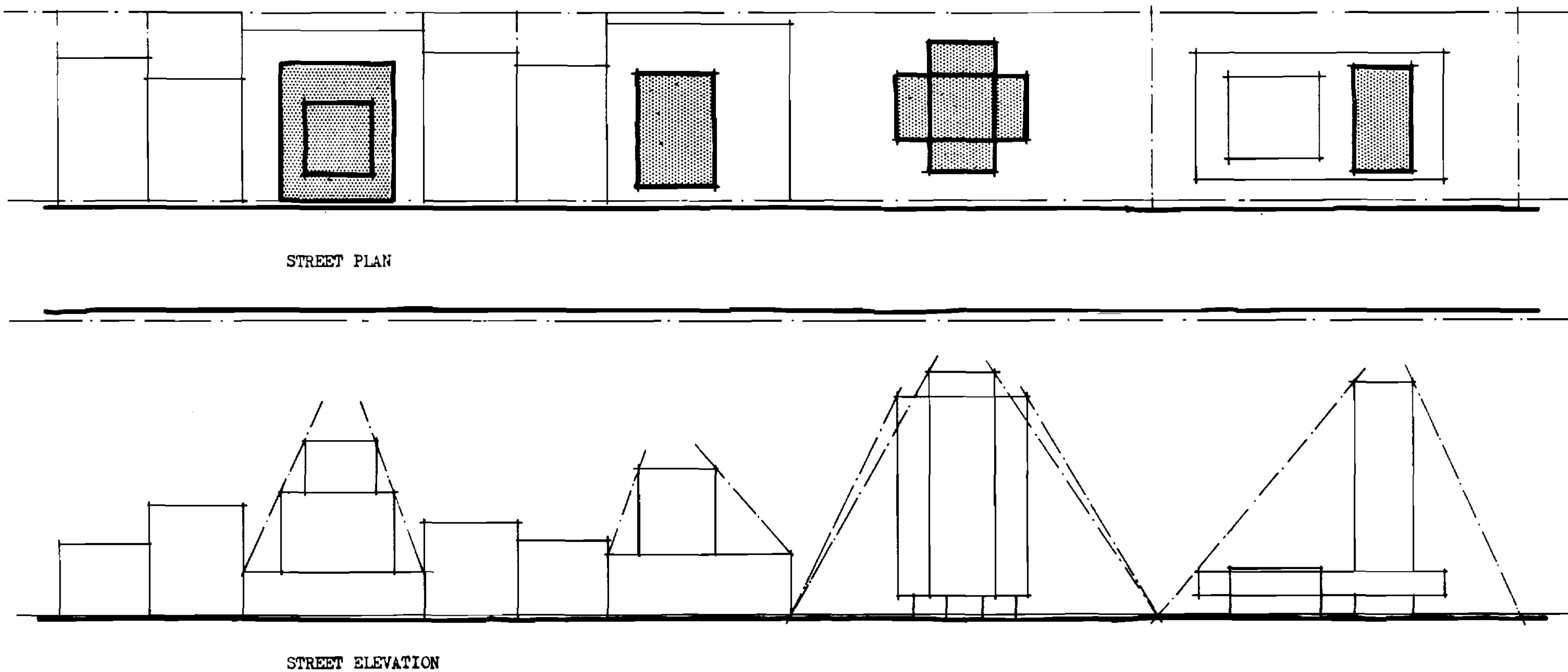


FIGURE 19

VERTICAL AND AVERAGE VERTICAL LIGHT ANGLE CONTROLS

BR 3906-15

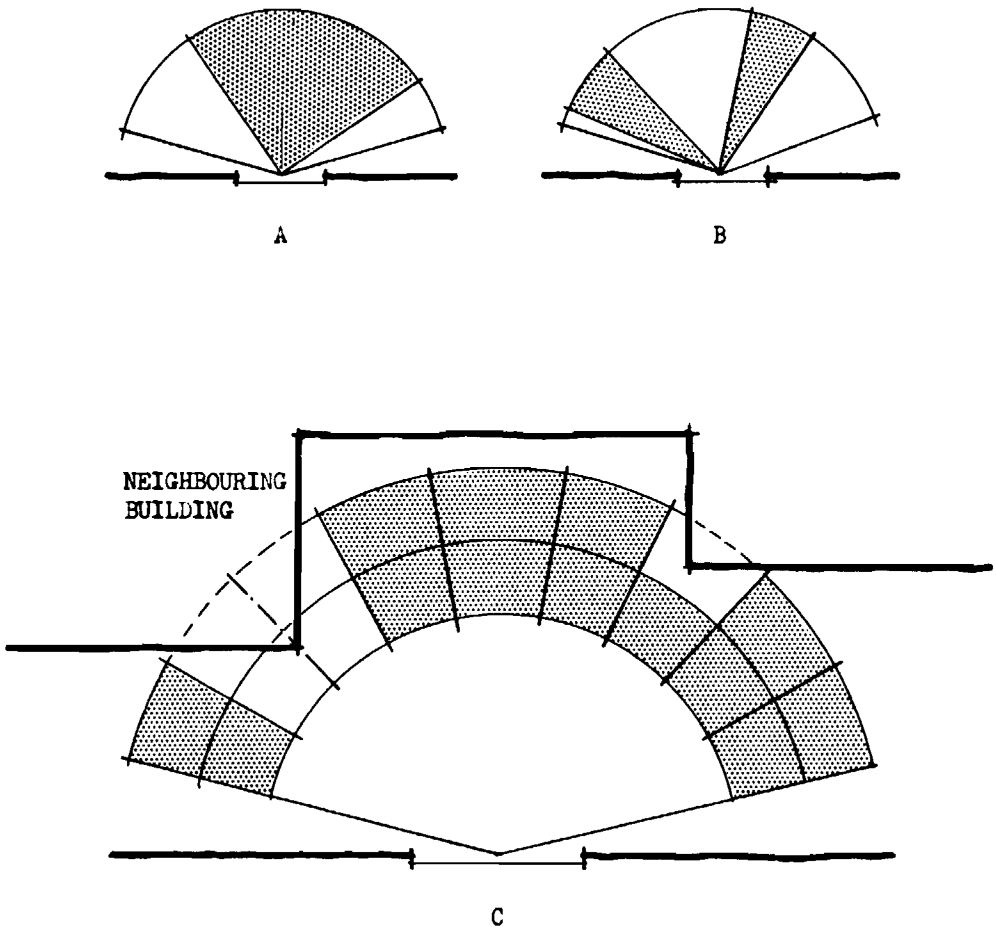


FIGURE 20

HORIZONTAL AREAS OR ANGLES OF DAYLIGHT ACCESS

BR 3906-16

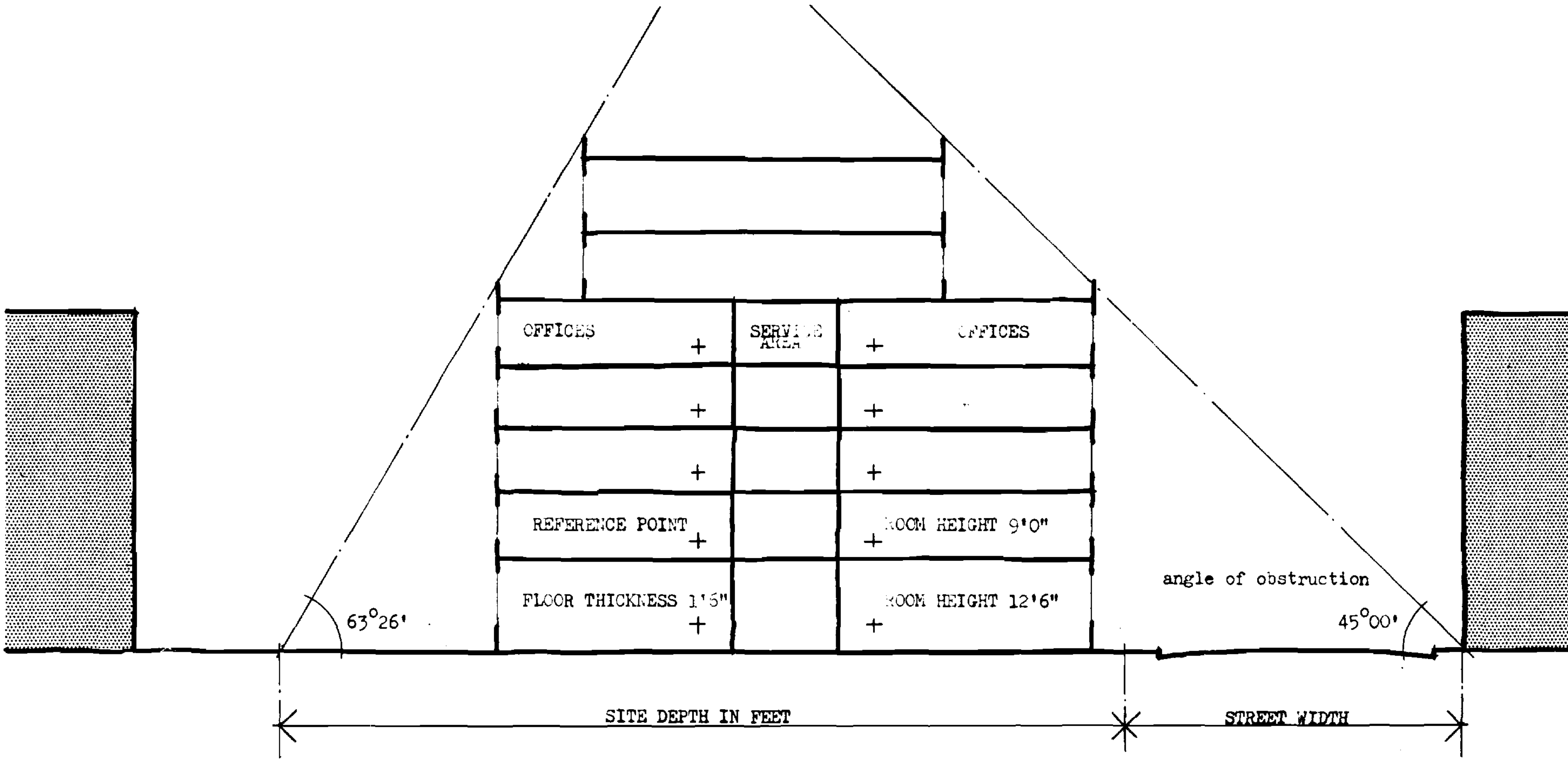


FIGURE 21

THE FORM OF DEVELOPMENT DESCRIBED BY THE DAYLIGHTING REQUIREMENTS OF THE PLAN FOR THE METROPOLITAN REGION: PERTH AND FREMANTLE

BA 390L-17

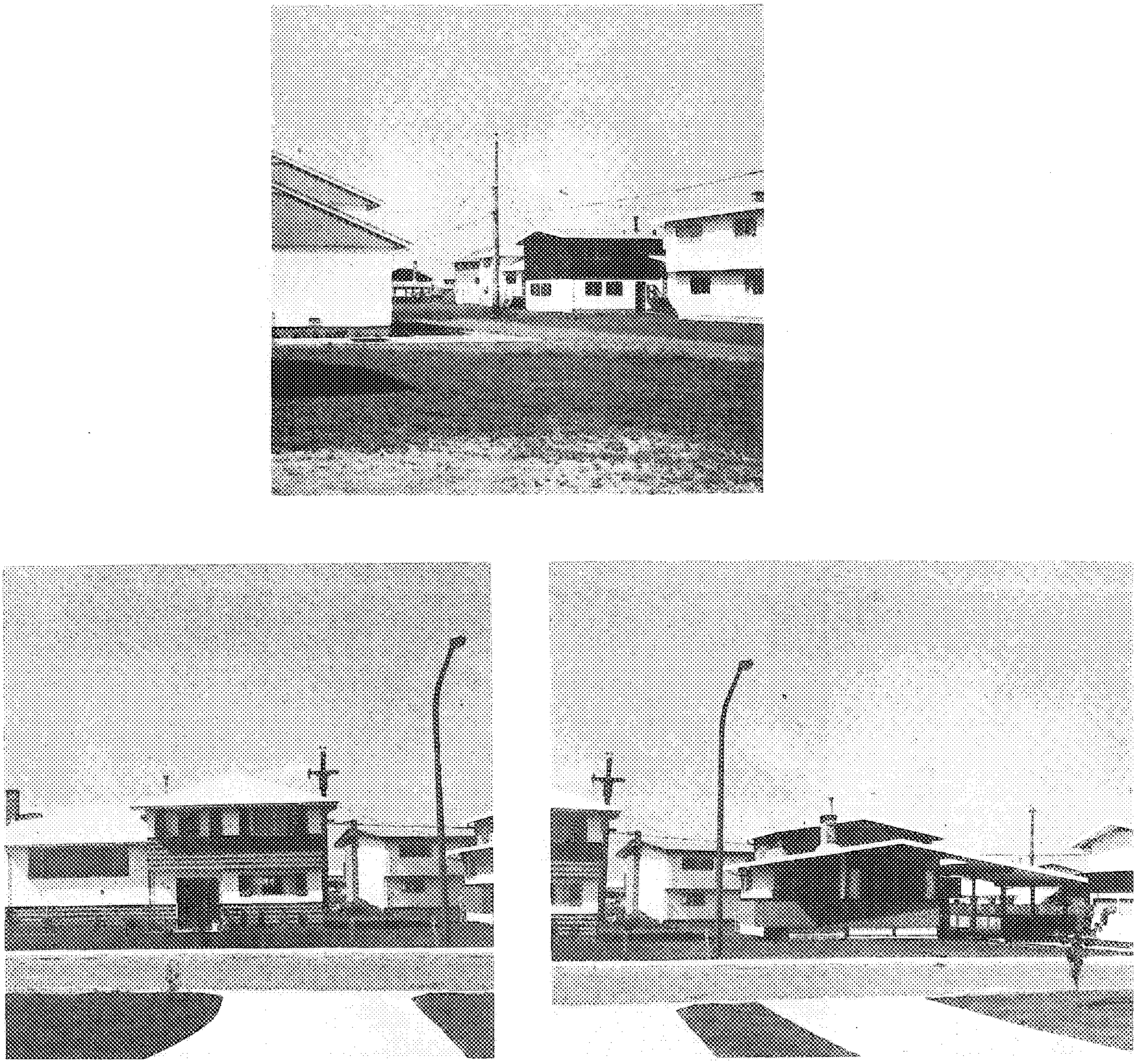


FIGURE 22 A SUBURBAN AREA CONSIDERED FOR DAYLIGHTING STUDY

The flat land is covered with similar new and widely spaced single family detached dwellings that present, due to their juxtaposition and equal height, a fairly uniform skyline. (The representative siting data is: sideyard spacing = 24 feet, average height = 18 feet, distance between houses across the street = 138 feet, distance between houses at rear = 80 feet.)

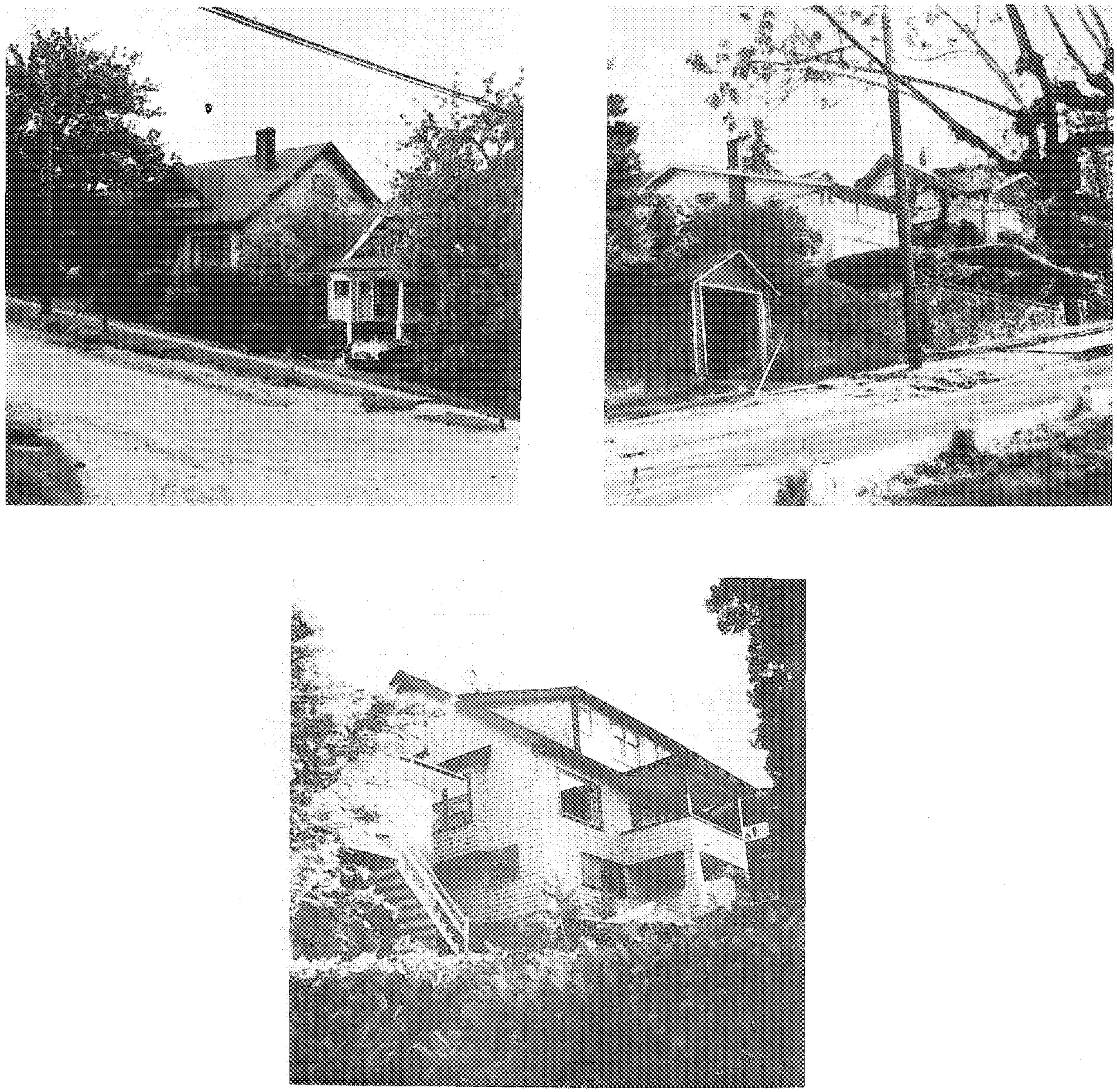
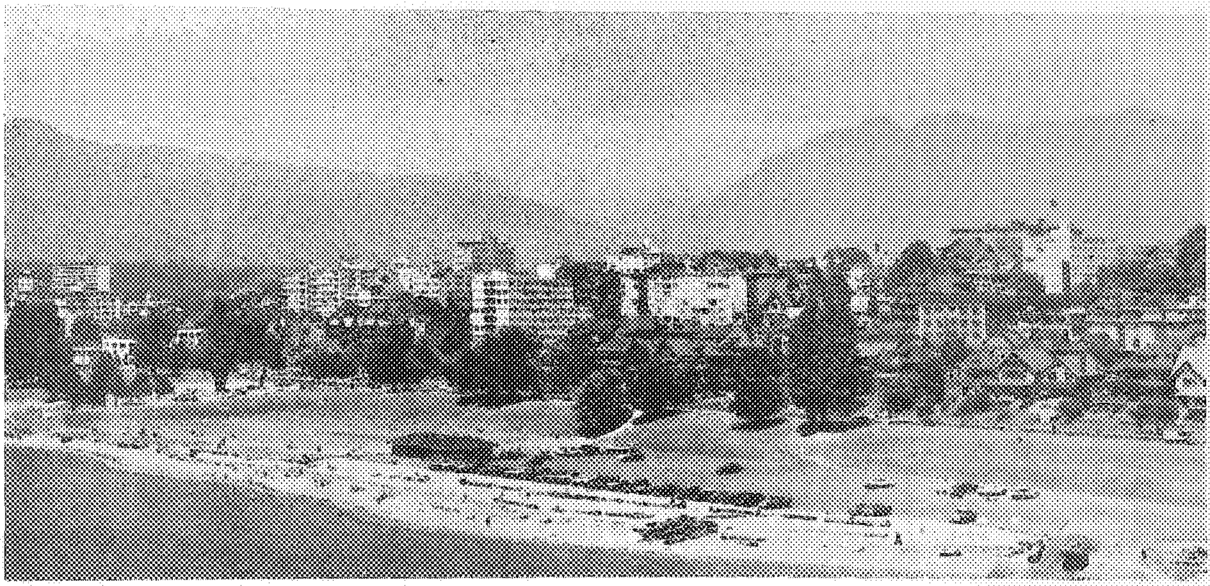
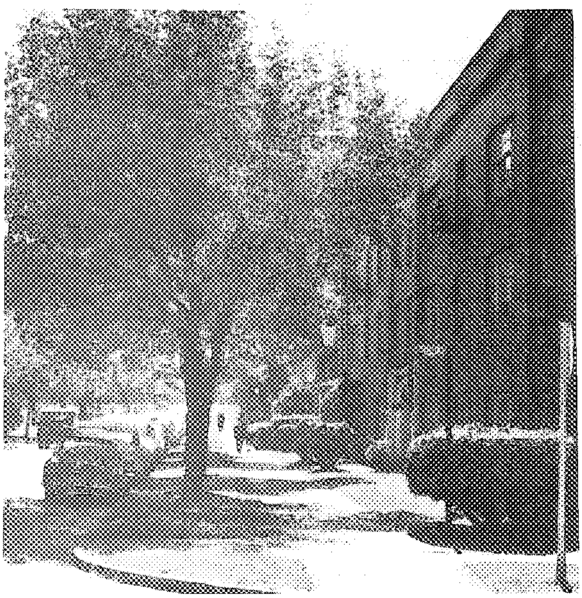


FIGURE 23 A HILLY URBAN AREA CONSIDERED FOR DAYLIGHTING STUDY

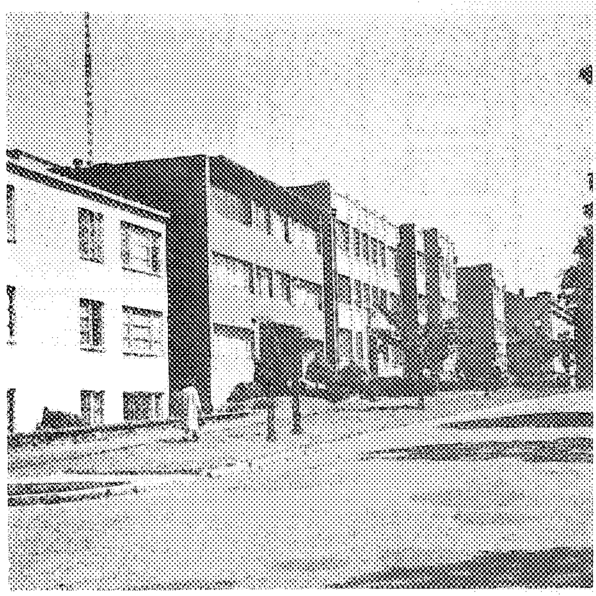
The area contains old and closely spaced single family dwellings on grades from 10 to 20 per cent. The permanent growth is heavy. (The representative siting data is: sideyard spacing = 16 feet, average height = 25 feet, distance between houses across the street = 170 feet, distance between houses at rear = 80 feet.)



a



b



c

FIGURE 24 THE AREA SELECTED FOR THE DAYLIGHTING STUDY

The area selected for the study is a downtown Vancouver multiple-family dwelling area (22-a) of closely spaced old and new three-floor apartment buildings (22-b, c)* containing suites with a variety of outlook and exposure.

---

*These photographs show, respectively, streets C and B that are marked on Figure 25.

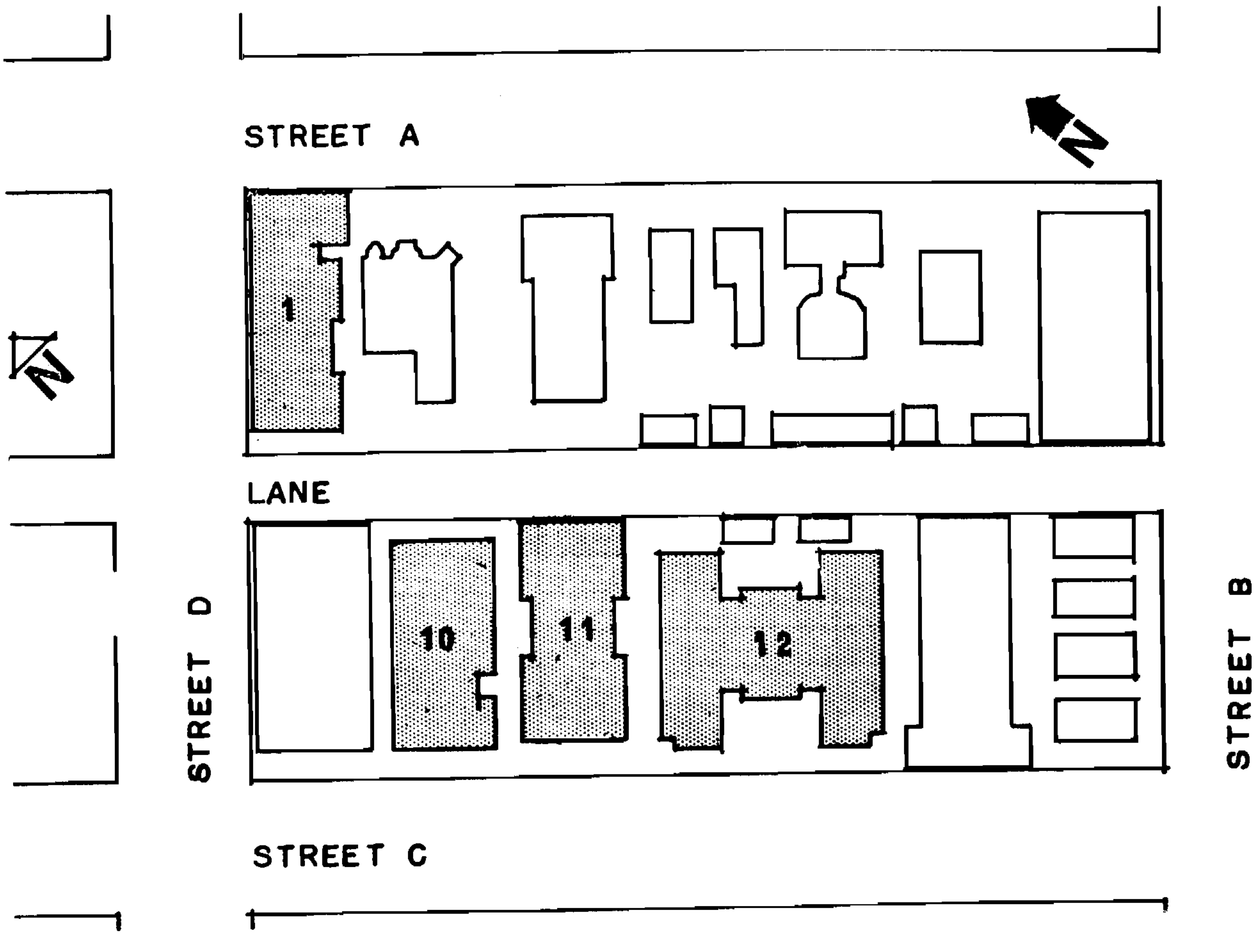


FIGURE 25

PLAN OF THE AREA CHOSEN FOR STUDY

THE PLAN SHOWS THE AREA IN DOWNTOWN VANCOUVER CONTAINING THE FOUR DESIRABLE BUILDINGS THAT COULD BE CHOSEN FOR EXAMINATION.*

* The buildings chosen are numbers 1, 10, 11, and 12.

BA 3906-1B

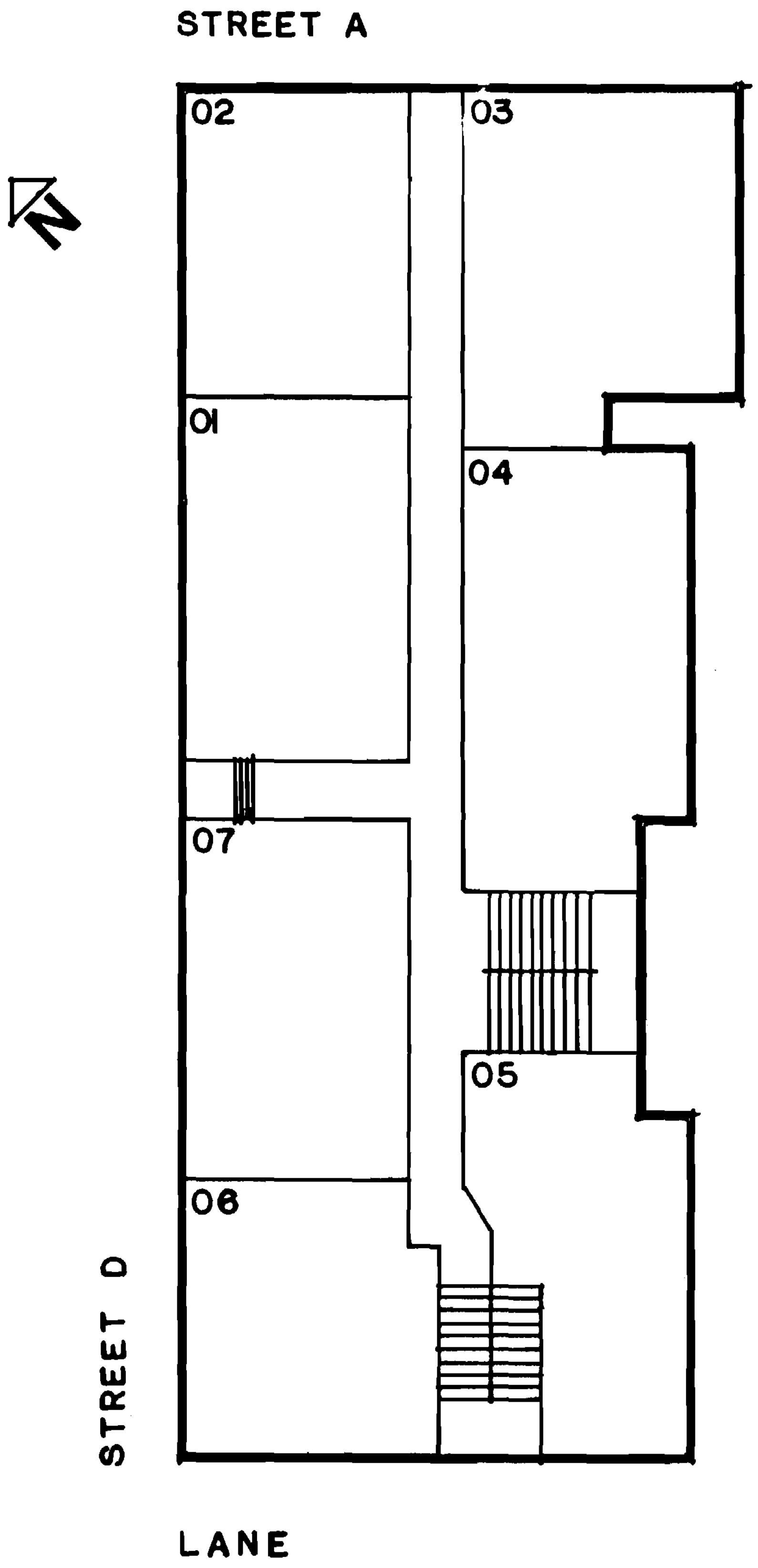


FIGURE 26

PLAN SHOWING TYPICAL FLOOR LAYOUT OF BUILDING NO. 1

BR 3906-19

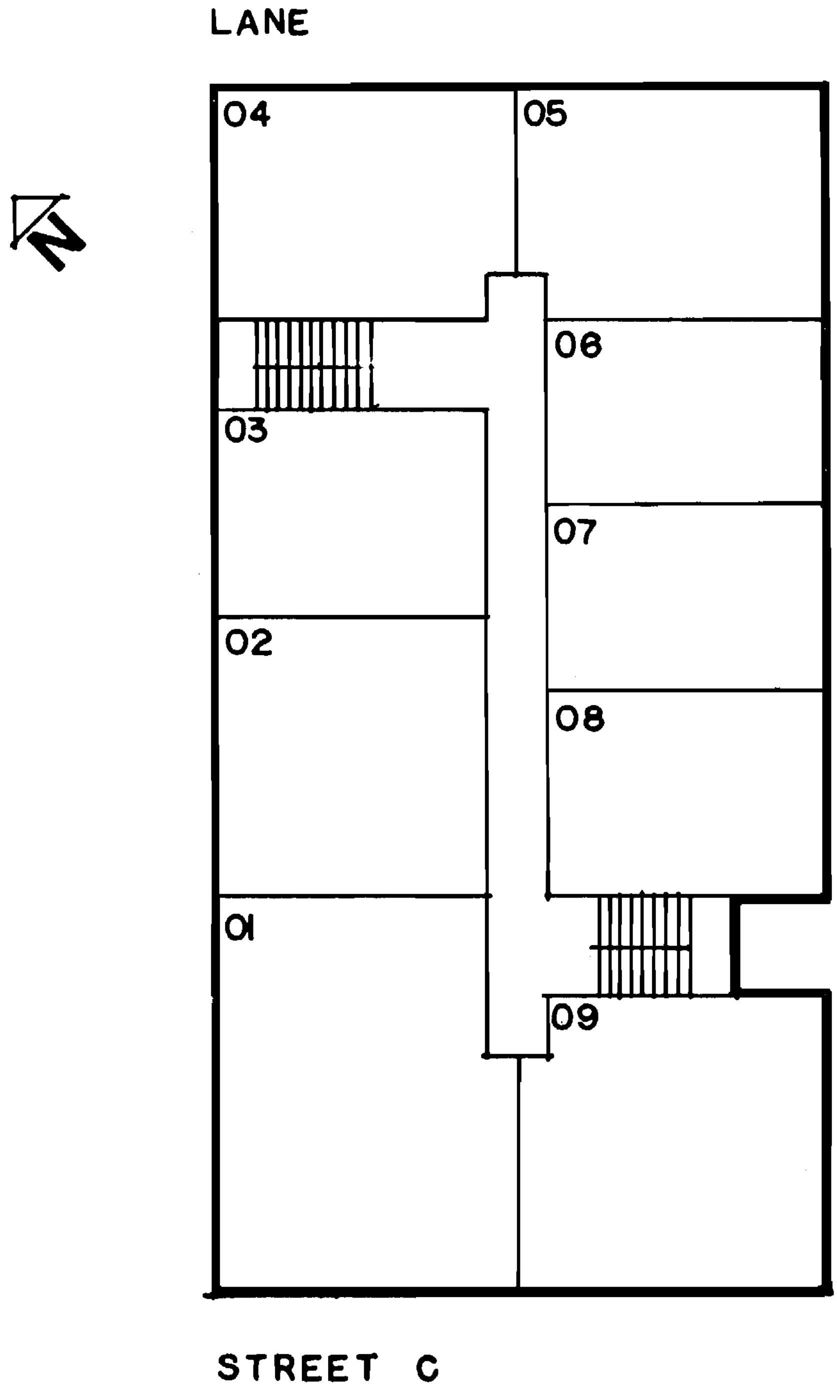


FIGURE 27

PLAN SHOWING TYPICAL FLOOR LAYOUT OF BUILDING NO. 10

BR 3906-20

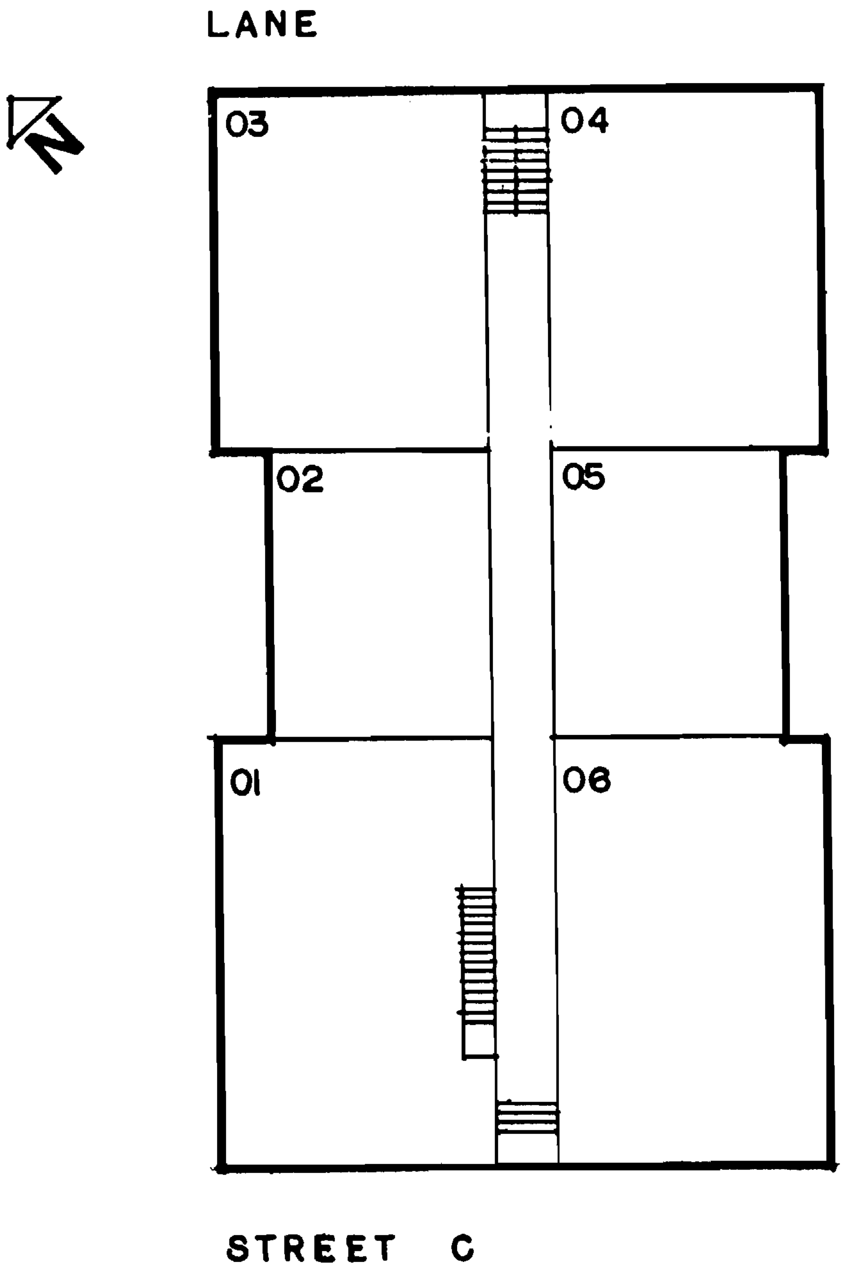


FIGURE 28

PLAN SHOWING TYPICAL FLOOR LAYOUT
OF BUILDING NO. 11

BR3906-21

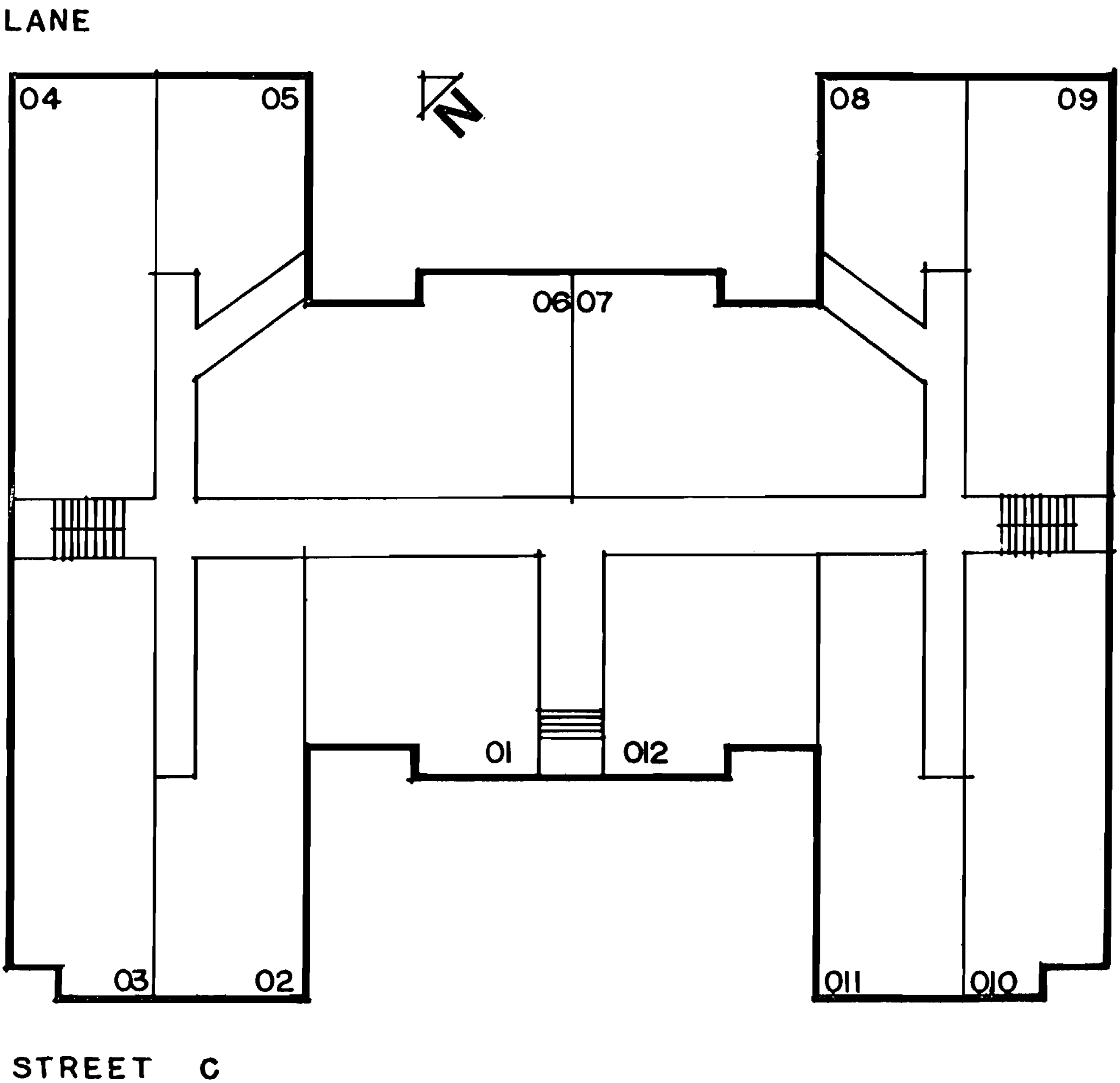


FIGURE 29

PLAN SHOWING TYPICAL FLOOR LAYOUT OF BUILDING NO. 12

BR 3906-22

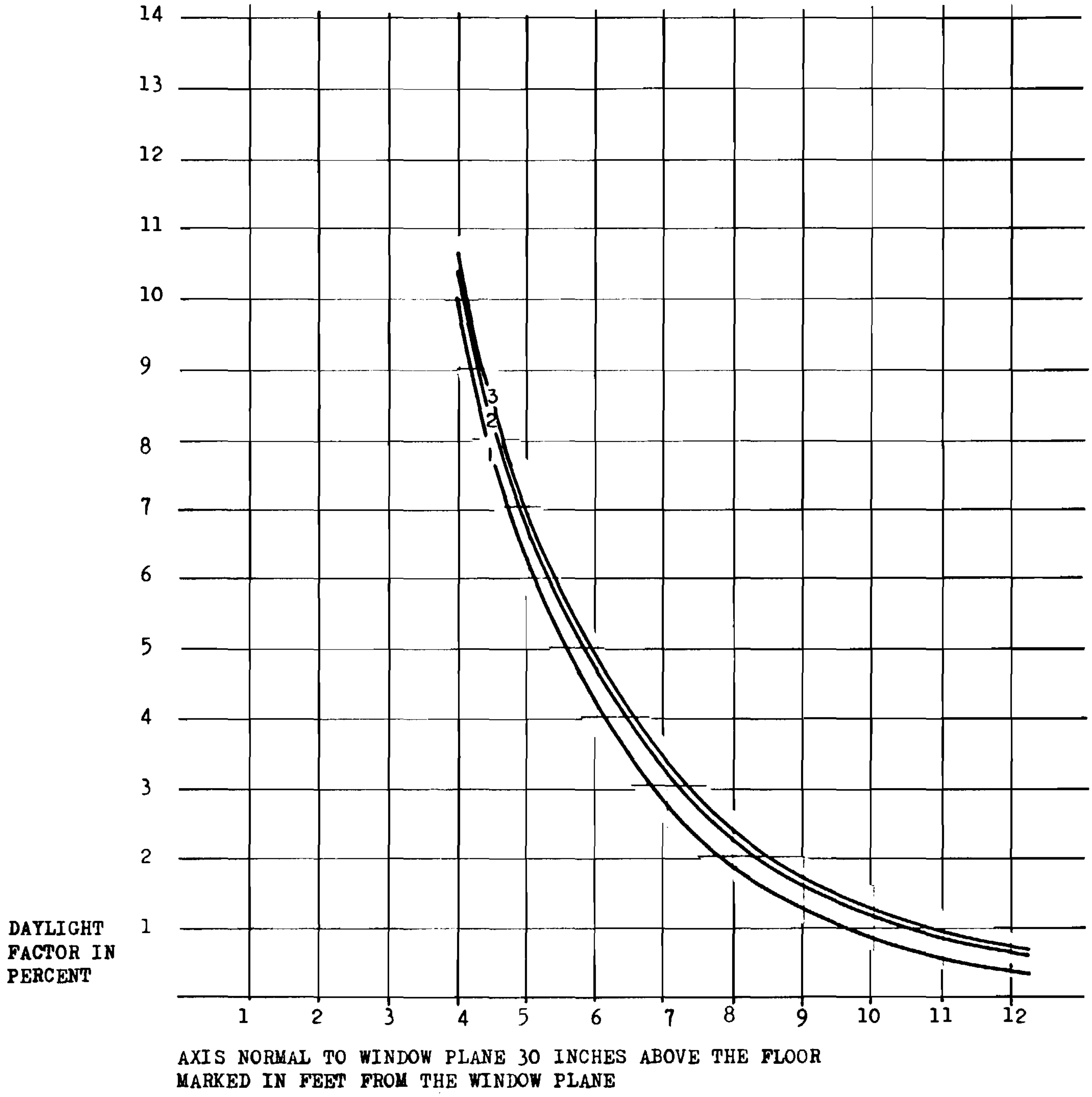


FIGURE 30

WALDRAM DIAGRAM ANALYSIS OF APARTMENTS 04, BUILDING NO. 11; LIVING ROOMS FACING NORTH TO LANE

Numerals shown on the curves indicate floor level

BR 3906-23

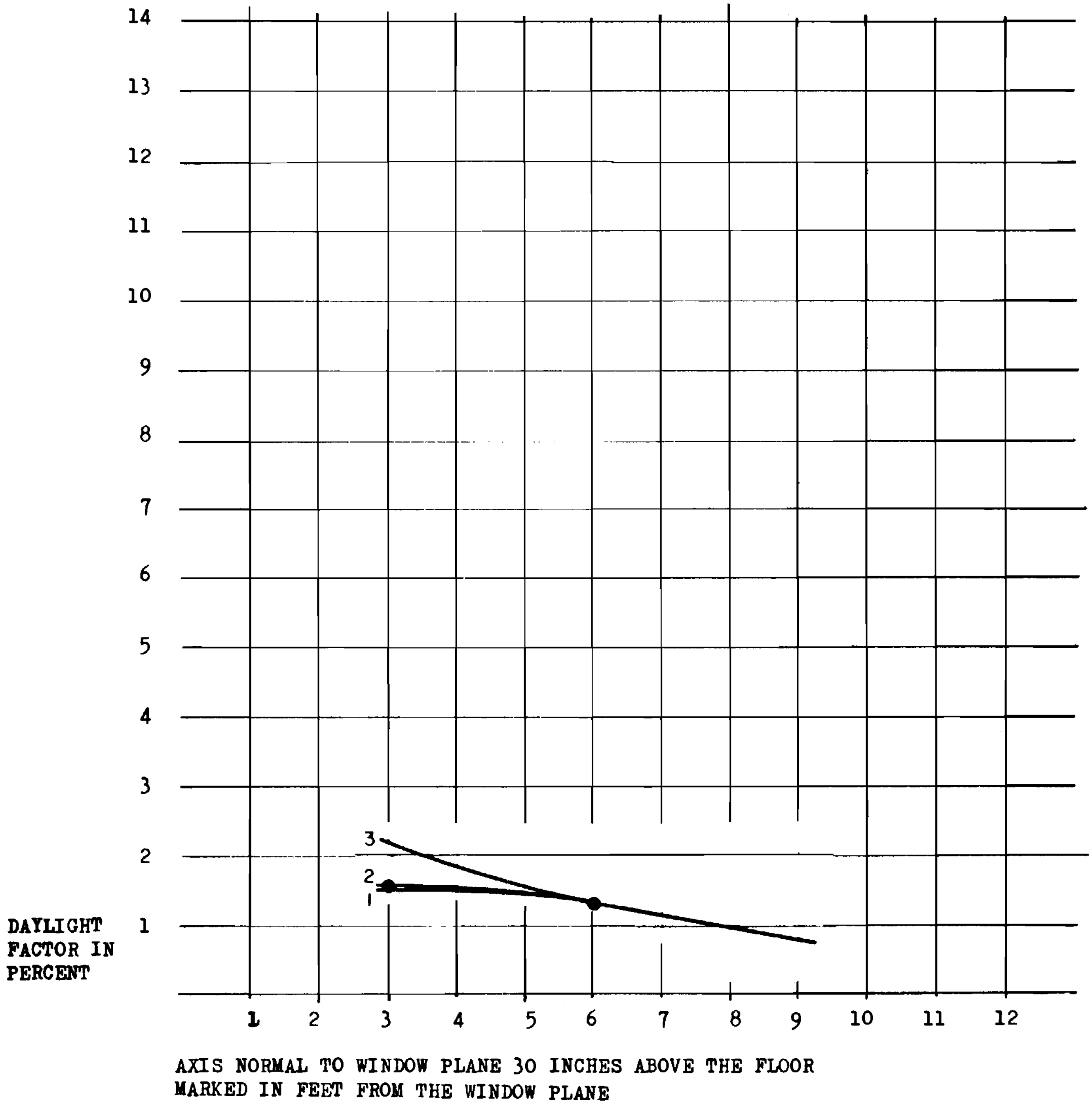


FIGURE 31

WALDRAM DIAGRAM ANALYSIS OF APARTMENTS 04, BUILDING NO. 11; LIVING ROOMS FACING EAST TO SIDEYARD.

Numerals shown on the curves indicate floor level

BR 3906-24

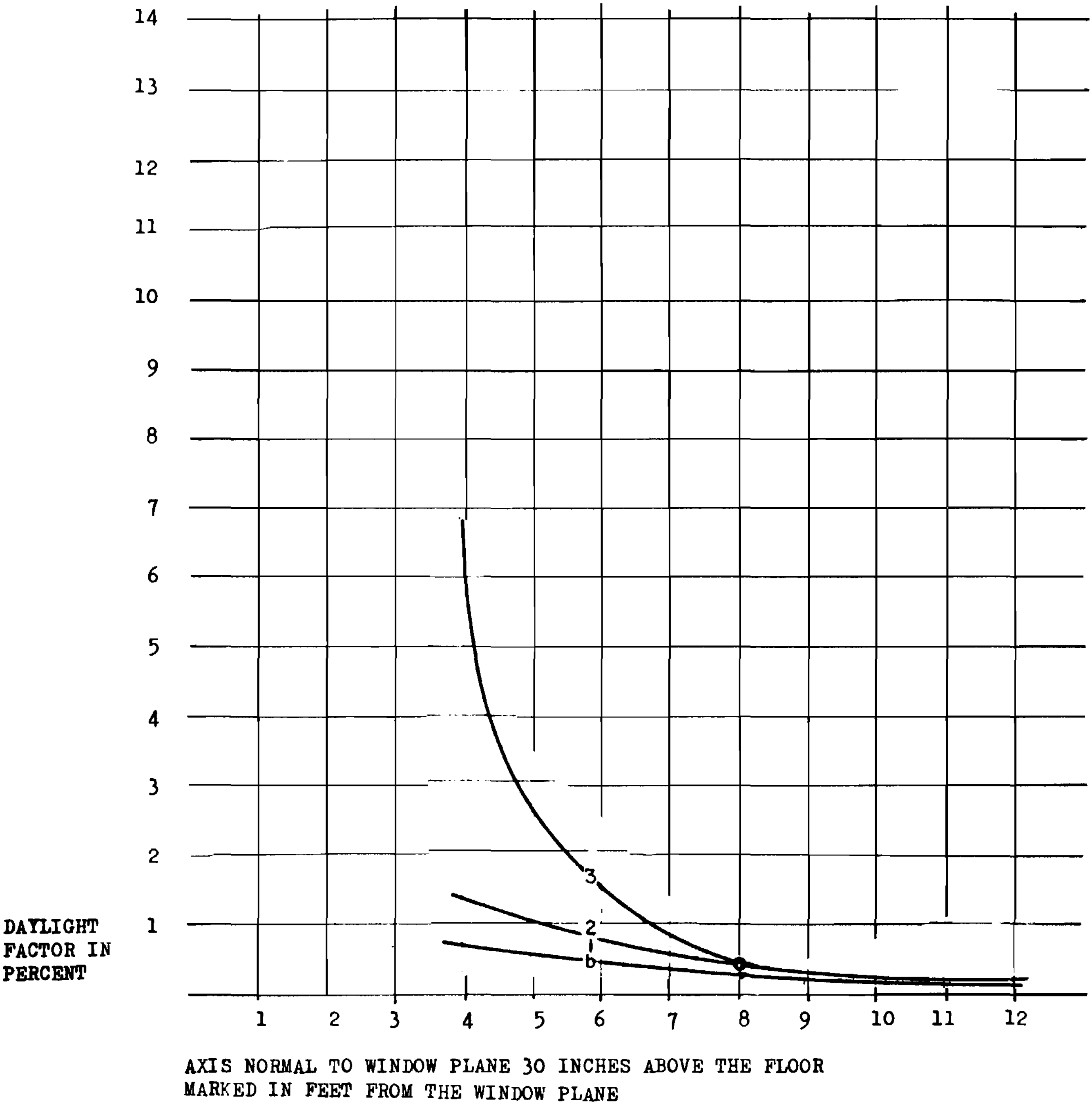


FIGURE 32

WALDRAM DIAGRAM ANALYSIS OF APARTMENTS 05, BUILDING NO. 11; LIVING ROOMS FACING EAST TO SIDEYARD

Numerals shown on the curves indicate floor level

BR 390L-25

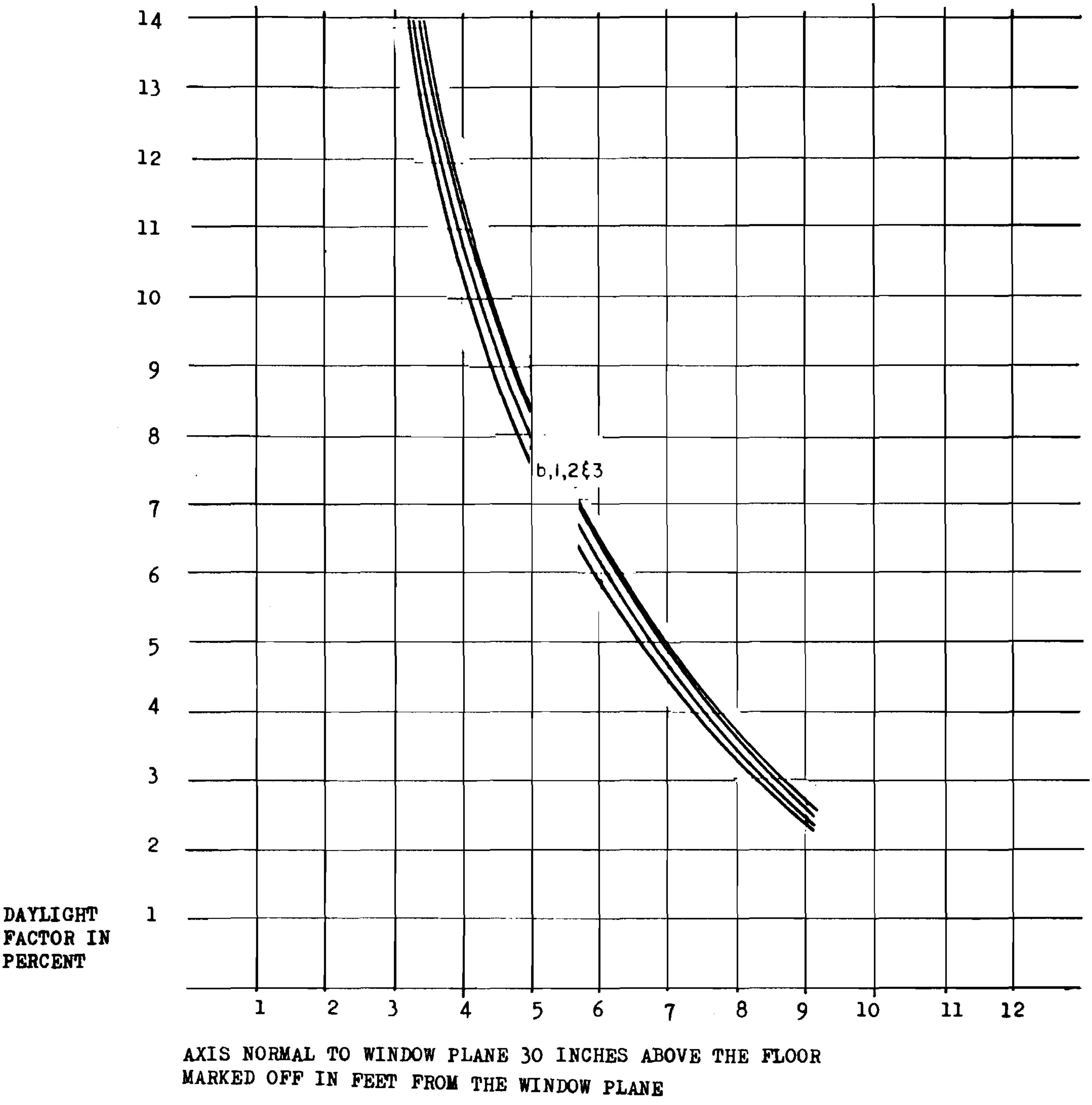


FIGURE 33

WALDRAM DIAGRAM ANALYSIS OF APARTMENTS 02, BUILDING NO. 1; LIVING ROOMS FACING NORTH TO ROAD

Numerals shown on the curves indicate floor level

BR 3906-26

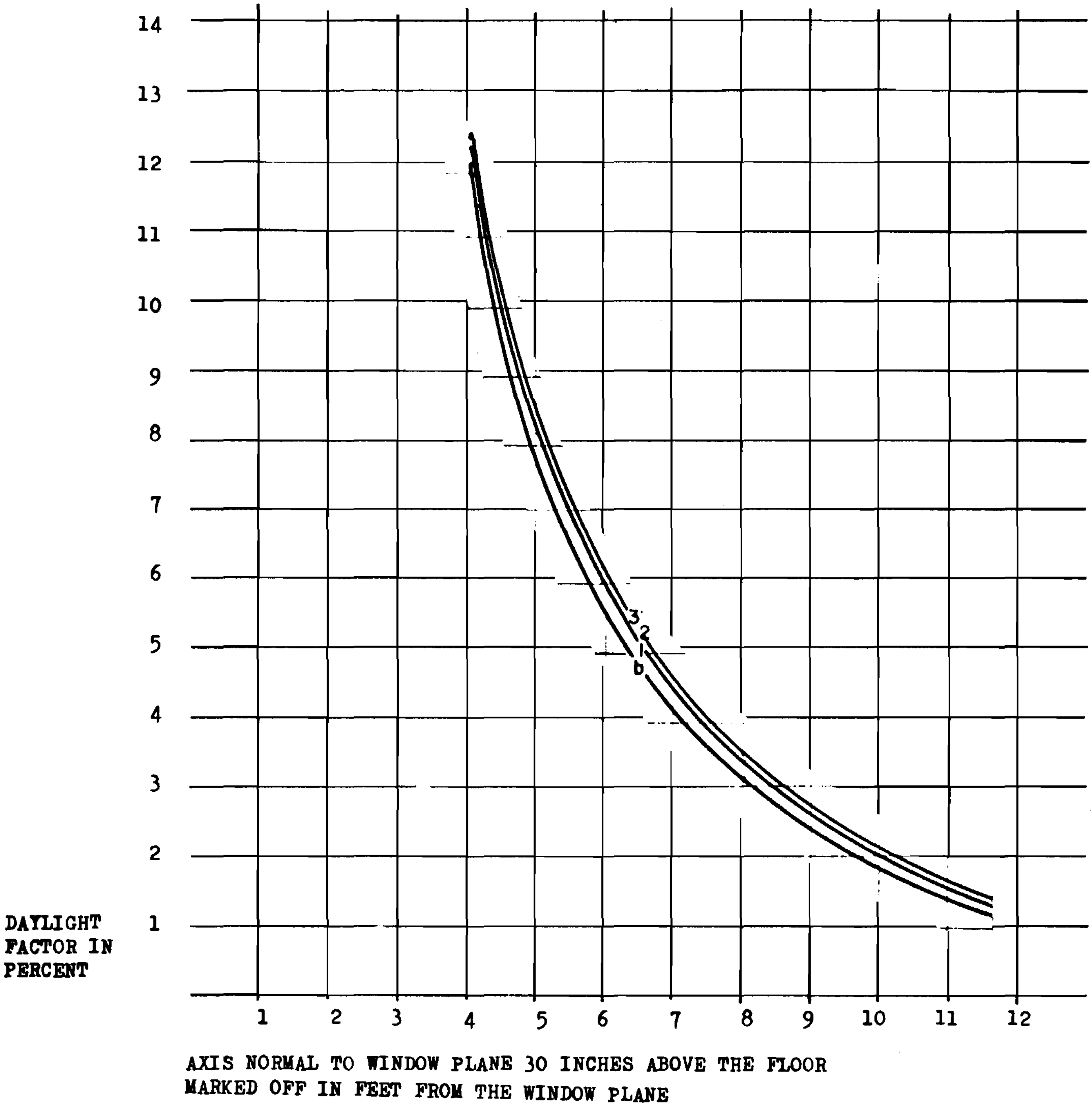


FIGURE 34

WALDRAM DIAGRAM ANALYSIS OF APARTMENTS 02, BUILDING NO. 1; LIVING ROOMS FACING WEST TO ROAD

Numerals shown on the curves indicate floor level

BR 3906-27

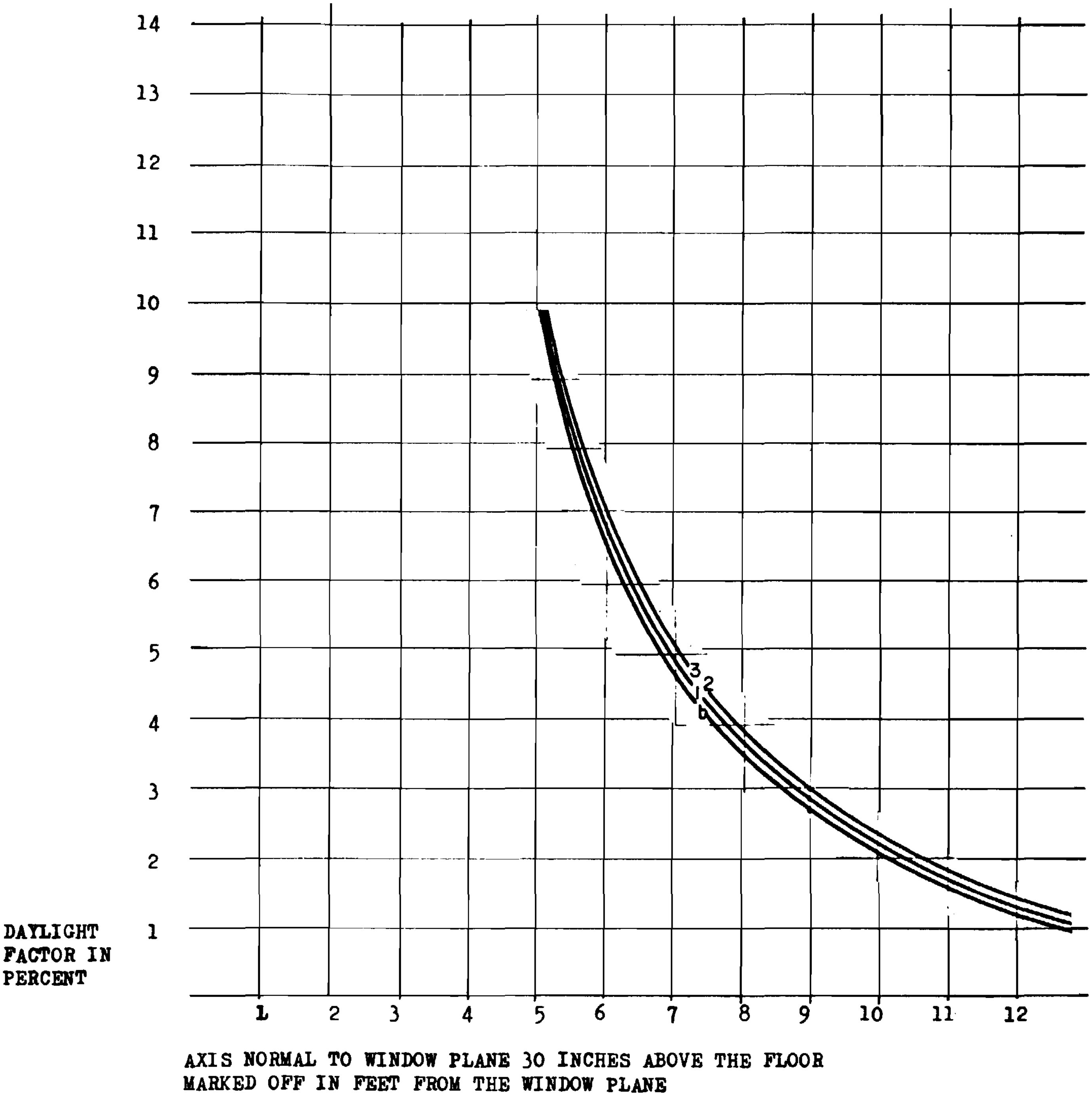


FIGURE 35

WALDRAM DIAGRAM ANALYSIS OF APARTMENTS 07, BUILDING NO. 1; LIVING ROOMS FACING WEST TO ROAD

Numerals shown on the curves indicate floor level

BR 3006-28

APPENDIX A

DETERMINATION OF DAYLIGHT DESIGN VALUE FOR OTTAWA, ONTARIO

Appendix A reproduces part of a study by M. Galbreath of the Division of Building Research, National Research Council, concerned with daylight design values in general and the daylight design value for Ottawa in particular. The following is quoted from a draft copy of the study titled: Selection of Design Criteria for Natural Illumination.

The minimum daylight design figures for Ottawa are derived from hourly readings of solar radiation in calories/sq cm taken over a four-year period from 1958 to 1961. Conversion was made on the basis:

lumens/sq ft = cal/sq cm/min x 7000

The daylight working hours are assumed to extend from 8 am to 5 pm. In the latitude of Ottawa, 45° 24', the sun sets before 4:30 pm during December and part of November. Those hours in which the sun had set before 4:30 were excluded from the calculation as these cannot be considered hours of daylight. The factor can probably be ignored in more southern latitudes, but will become of considerable significance in Canada's northern territories.

The figures for daylight availability on an unobstructed exposed horizontal plane in Ottawa, based on conversion from radiation to illumination units, are shown in Table A-I. A comparison of these figures with derived daylight design levels for a number of other cities in both northern and southern hemispheres, with notes on latitude and rainfall, is the subject of Table A-II.

TABLE A-I

DAYLIGHT AVAILABILITY IN OTTAWA, ONTARIO, FOR DAYLIGHT WORKING HOURS (8 am to 5 pm)

Incident Exterior Illumination on a Horizontal Plane Lumen/sq ft	Percentage of Total Time Illumination Exceeded Stated Value
100	98.7
250	96.5
500	91.9
1,000	81.7
2,500	60.2
5,000	33.0
10,000	0

TABLE A-II

DAYLIGHT AVAILABILITY FIGURES ESTABLISHED FOR CITIES IN NORTHERN AND SOUTHERN HEMISPHERES

City	Latitude	Annual Rainfall in.	Daylight Availability Lumen/sq ft	Percentage of Daylight Working Hours
Northern Hemisphere				
Teddington, England	51°30'	24.47	500	85
Ottawa, Canada	45°24'	34.89	500	90
Ann Arbor, Mich., USA	42°17'	-	500	90
Southern Hemisphere				
Hobart, Australia	42°53'	25.03	425	90
Melbourne, "	37°49'	25.89	500	90
Canberra, "	35°18'	23.92	600	90
Adelaide, "	34°56'	21.09	600	90
Cape Town, S. Africa	34°30'	25.01	750	96
Sydney, Australia	33°52'	44.80	625	90
Perth, "	31'57'	35.99	750	90
Brisbane, "	27°28'	40.09	800	90
Pretoria, S. Africa	26° 0	-	1000	97

APPENDIX B

THE FINAL FORM OF THE INTERVIEW SCHEDULE

QUESTIONNAIRE

NATURAL LIGHT IN APARTMENTS

QUESTIONNAIRE

NATURAL LIGHTING OF APARTMENTS

Date of Interview: ____________________ Time: __________ AM PM Night

Address: Apt ________ Bldg No. __________ Orientation to lane ____ Street ___ Yard ___

Weather Conditions: __________ Clear Cloudy Overcast Illumination ____ F.C. Park Roof

Number in Household ________ Adults ___ Preschool ____ School ____ Other _________

Respondent allowed interview and readings for kitchen living room bedrooms

Respondent: Mrs. Mr. Miss. ______________ Status: wife mother spinster
husband father bachelor

Employment of Respondent: ________________ Retired Housewife

Working Hours: Days Nights Time at Home: Weekdays _____ Evenings
Weekdays _____ Part Most

Wears Glasses: Yes No Only for Reading

Comment: ____

____

____

****

Data Summary:

	Reading At Room Centre	Daylight Factor
Kitchen:	____________________	______________
Living Room:	____________________	______________
Bedroom:	____________________	______________
Bedroom:	____________________	______________

Comment: ____

QUESTION NO. 1

How would you describe the light in the kitchen in the daytime?

Good: ____________________

Adequate: ________________

Unsatisfactory: ___________

Particular Complaints: ____

____

____

____

____

____

____

Interviewer's Comments: ____

____

____

Furnishings: Light____ Neutral____ Dark______ ________________________

Walls: Light____ Neutral_____ Dark______ ________________________

Ceiling: Light____ Neutral_____ Dark______ ________________________

Meter: Meter Slide: ______________________ Reading: _______________

Filter: 50%_____ 10%______ 1______ 2__________ 3__________

Amps: ____________________________________

QUESTION NO. 2

How would you describe the light in the living room in the daytime?

Good: ______________

Adequate: ______________

Unsatisfactory: ________

Particular Complaints: ____

____

____

____

____

____

____

Interviewer's Comments: ____

____

____

Furnishings:	Light _____	Neutral _______	Dark _______	_________
Walls:	Light _____	Neutral _______	Dark _______	_________
Ceiling:	Light _____	Neutral _______	Dark _______	_________

Meter: Meter Slide: ______________ Meter Reading: ______________

Filter: 50% ______ 10% ______ 1 ________ 2 ______ 3 ______

Amps: ______________________________

Other Comment:

QUESTION NO. 3

How would you describe the light in the bedroom in the daytime?

Good: ____________

Adequate: _________

Unsatisfactory: ____

Particular Complaints: ____

____

____

____

____

____

____

Interviewer's Comments: ____

____

____

Furnishings:	Light ______	Neutral ______	Dark ______	____________
Walls:	Light ______	Neutral ______	Dark ______	____________
Ceilings:	Light ______	Neutral ______	Dark ______	____________

Meter: Meter Slide: _______________ Meter Reading: _______________

Filter: 50 % _____ 10% _______ 1 _______ 2 _______ 3 ______

Amps: __________________________________

Other Comment:

QUESTION NO. 4

Does the sun ever enter the kitchen? Yes_____ No_____ Reflection_________

Summer______ Morning________ Afternoon_________

Winter_______ Morning________ Afternoon__________

Particular Comment ____

____

____

____

Does the sun ever enter the living room? Yes______ No______ Reflection_______

Summer______ Morning_______ Afternoon___________

Winter_______ Morning_______ Afternoon____________

Particular Comment ____

____

____

____

Does the sun ever enter the bedroom? Yes______ No_______ Reflection_______

Summer______ Morning_______ Afternoon__________

Winter_______ Morning________ Afternoon__________

Particular Comment ____

____

____

____

QUESTION NO. 5

How often do you have to use the electric lights in the different rooms?

Kitchen: Rarely____S__W__ Occasionally ____S__W__ Most of time____S__W__

Living Room: Rarely____S__W__ Occasionallv ____S__W__ Most of time____S__W__

Bedroom: Rarely____S__W__ Occasionally ____S__W__ Most of time____S__W__

Particular Comment ____

____

____

____

QUESTION NO. 6

Do you have the use of any outdoor space?

Roof______________________

Patio______________________

Balcony______________________

Lawn______________________

Other______________________

Particular Comment ____

____

____

____

____

QUESTION NO. 7

If you could have good natural light in only one room, which room would that be?

Kitchen__________

Living___________

Bedroom_________

Why?____

____

____

____

QUESTION NO. 8

What kind of housing did you have before coming here?

House__________

Apartment_____

Other__________

How does your present accommodation compare with what you had before?

____

____

____

____

____

QUESTION NO. 9

If you could have the sun in only one room which room would that be?

Kitchen____________

Living Room________

Bedroom____________

Why?____

QUESTION NO. 10

Is there any particular direction in which you think it would be desirable to have the windows of an apartment facing?

North_________

South__________

East___________

West___________

Why?____

QUESTION NO. 11

In general, how do you find the outlook from your apartment?

Interviewer's Comments