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Handbook On

Energy Conservation in Buildings and Building Services

BUILDING AND CONSTRUCTION AUTHORITY
THE DEVELOPMENT & BUILDING CONTROL DIVISION (P.W.D.) SINGAPORE

CONTENTS

PREFACE

The Handbook on Energy Conservation in Buildings and Building Services was first published in December 1979 to complement the Building Control (Space, Light and Ventilation) Regulations which was gazetted in August 1979.

As a result of the feedback from the users of the Handbook and also because of the continuing development in the field of energy conservation, several areas in the Handbook had to be updated to keep abreast with changing needs. This revised edition has thus been prepared to meet these needs and it is meant to supersede the first edition of the Handbook.

In contrast to the first edition, in which chapters were arranged under the titles of “General Building”, “Air-conditioned Building” and “Non Air-conditioned Building”, this revised Handbook has been re-organised to cover specific topics of energy conservation, such as lighting, air-conditioning, etc, under separate chapters. Apart from attaching greater importance to the individual topics, this arrangement also lends itself to greater ease of reference.

In general, most of the topics have been given a “face-lift”. Besides being re-arranged and updated, some topics have also been expanded. Ample clarifications have been added to the text to help the users appreciate better the rationale of the standards.

In this revised Handbook, two major changes have been introduced, viz. a new standard on OTTV for roof and a new method of computing the shading coefficients of external shading devices.

The new standard on OTTV for roof, which is covered in chapter V, is merely an extension of the concept of OTTV for envelope. Its incorporation in the revised Handbook is the result of the growing trend towards designing buildings with high atriums and vast skylights.

The new method of computing the shading coefficients of external shading devices is explained in Appendix II. According to the old method prescribed in the first Handbook, the shading coefficient of a shading device depends, to a certain extent, on its form factor which is a geometrical characteristics of the device. In considering the form factor, different standard formulae have to be used for horizontal, vertical and egg-crate types of shading devices. However, such formulae are only available for simple standard designs. Where the devices deviate from the standard forms, it would not be possible to calculate their form factors, and hence their shading coefficients. To overcome this difficulty, a simplified method of computation is adopted. This will make the computation of shading coefficient much more straight-forward compared to the old method.

In preparing this revised Handbook, reference was made to the following: -

Handbook on Energy Conversation in Building and Building Services
- December 1979 Edition.

Singapore Standard CP 24 Code of Practice for Energy Conservation in Building Services.

ASHRAE Standard on Energy Conservation in New Building Design
- 1980 Edition.

Management in the Design of New Buildings
- Public Works Department of Western Australia.

CHAPTER I INTRODUCTION

1.1 Aim

The aim of this Handbook is to provide a set of guidelines to assist architects and professional engineers in their submission of plans and calculation to the Development & Building Control Division in connection with the energy conservation requirements incorporated in the Building Control (Space, Light & Ventilation) Regulations. With the exceptions of those standards abstracted from the building regulations, the recommendations contained in this Handbook are meant to be used as a guide and not as mandatory requirements.

1.2 Scope

1.2.1

Apart from outlining some broad principles on energy conservation in buildings and building services, this Handbook focuses its attention on the following specific topics which are incorporated in the building regulations:

1) Lighting
2) Air-conditioning
3) Overall Thermal Transfer Value (OTTV) of Building Envelope
4) Roof Insulation and Roof OTTV
5) Thermal Comfort in Non Air-conditioned Buildings

1.2.2

Topics 1 and 4 are applicable to both air-conditioned and non air-conditioned buildings, while topics 2 and 3 are meant to apply to only air-conditioned buildings and topic 5 is devoted to non air-conditioned buildings.

1.3 Background

1.3.1

In September 1976, a seminar on “Energy Conservation in Building Design and Construction” was jointly organised by the Public Works Department, the Professional Engineers Board and the Board of Architects. Among the several technical papers disseminated at the seminar was one presented by the Building Control Division entitled “Recommended Standard for Design and Evaluation Criteria for Energy Conservation in Buildings for Building Code”. In that paper, several recommendations on energy conservation measures were made, notably in the area of natural ventilation, air-conditioning and artificial illumination.

1.3.2

As a result of the seminar, a research grant of $22,000 jointly contributed by the Board of Architects and the Professional Engineers Board was set aside to finance research projects on energy conservation in buildings. Subsequently, the Building Control Division was requested to take upon the task of carrying out research on matters pertaining to energy conservation with particular reference to areas which would help to substantiate the recommendations presented by the Division and to pave the way for their ultimate implementation.

1.3.3

To this end, a Committee was set up under the chairmanship of the Assistant Director of Building Control with representatives from the University of Singapore, the Singapore Institute of Architects, the Institution of Engineers Singapore, the Association of Consulting Engineers, the Public Utilities

Board and some other Government departments and statutory boards. The work of the Committee had been exhaustive; apart from weighing the effects of every probable energy conservation option, the Committee undertook a 2-year research project to substantiate its recommendations with factual evidence. Having completed a thorough analysis and evaluation, the Committee presented its recommendations which were incorporated into the Building Control (Space, Light & Ventilation) Regulations.

1.3.4

After the research project was completed, the BCD Committee assumed a new role to serve as a standing committee to review and revise the energy conservation standards as and when the need arises. As a result of its continuing effort in upgrading the standards, several new developments have been incorporated into the present building regulations.

CHAPTER II LIGHTING

2.1 General Principles of Efficient Lighting Practice

Lighting not only uses a significant proportion of the electricity consumed in most buildings, but also constitutes a large portion of the air-conditioning load in air-conditioned buildings. As such, lighting installation should be carefully designed so as to achieve the desired illumination level and visual effect with a minimum requirement of energy. This can be achieved by limiting the installed lighting power load through the use of efficient lighting equipment and the maximum utilization of daylight.

2.2 Choice of Light Source

2.2.1

The use of light source depends on the nature of the installation and the specific task preformed. The designer should be able to make the appropriate choice from the many light sources available on the market.

The following table shows the significant differences in the efficiency ratings of various lighting sources:-

Characteristics of light sources for general lighting

Lamp	Tungsten filament	Tungsten halogen	Low pressure sodium	High pressure sodium	High pressure mercury fluorescent	Hot cathode tubular fluorescent	Compact fluorescent	Mercury halide
Luminous efficacies* + (1m/W)	8-18	17-22	100-180	80-130	40-60	45-95	50-55	65-85
Wattage range (W)	25-1500	100-2000	10-200	35-1000	50-2000	4-125	7-25	150-10000
Nominal life +(h)	1000	2000	10000	7500	7500	7500	5000	2000-6000
Need for control gear	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Colour rendering	Good	Good	Bad	Fairly good	Fairly good	Fair to good	Good	Fairly Good
Available with internal reflector coating	Yes	No	No	Yes	Yes	Yes	No	Yes
Operating Position	Any	Horizontal	Horizontal=	Any	Any	Any	Any	Some restrictions
Correlated colour temperature (K)	1800-3000	2800-3100	N/A	2500	4000	2700-6500	2800-3000	3600-4400

Note:
*Efficacies vary considerably within a given range and are based on initial (100 hrs) lumen output and exclude control gear losses.
+ For up-to-date information on this characteristic, reference should be made to manufacturers' catalogues.
= Certain of the low wattage lamps can be used vertically.

2.2.2

High lamp efficacies are necessary to ensure a low installed lighting load. Recommended minimum lamp efficacies are given in the following table.

Recommended Minimum Lamp Efficacies

Type of Lamp		Minimum Efficacy (Lumens per Watt)
1	Fluorescent (above 32W)	60
2	Fluorescent (32W and below)	35
3	Mercury (MBF)	38
4	Metal Halide (MBI)	60
5	High Pressure Sodium (SON)	65

2.2.3

The general use of incandescent lamps should be discouraged. In general, the normal light source should be the fluorescent tube. In "down light" installation, high-pressure discharge lamps can be used. In large high bay areas, high-pressure discharge lamps should be used as the prime source of illumination.

2.3 Choice of Luminaires

2.3.1

While it is essential in the design of an energy efficient lighting system to use the correct type of light sources, it is equally important to select the right type of luminaires that are efficient, having light distribution characteristics appropriate for the tasks and the environment and not producing discomfort glare or serious reflection. The most efficient luminaires for fluorescent lamps that at the same time meet the requirements of glare limitation are the mirror reflector or prismatic type, whereas for high-pressure discharge lamps, luminaires should have high quality anodized aluminium reflectors.

2.3.2

In general, only luminaires of high efficiency having a high downward light output ratio should be used. The design of fluorescent luminaire should be such that the tube wall temperature is maintained as close as possible to 40°C.

2.3.3

The ballasts used in fluorescent and other luminaires should be of the low loss type. All luminaires should be power factor corrected to a value greater than 0.85.

2.4 Localised Lighting

2.4.1

General ambient lighting of work places is comparatively less efficient. Often, the variation of activities at the work place requires a different degree of visual effort. For example, in a drawing office, task lighting should be provided specifically for the draughtsman to perform his work around the drawing table with a lower general background lighting. This can result in a great reduction of overall lighting load per unit floor area.

2.4.2

To incorporate localised lighting, the designer/professional engineer should determine the visual tasks that are expected to be performed in each space and the number of working locations where tasks will be performed prior to the design of the general illumination system. A thorough exchange of information among the parties concerned such as the developer, the architect and the designer/professional engineer is essential. Where it is felt that changes in the location of the task are likely to take place, some allowance should be made for the possible relocation of lighting equipment. Alternatively an overall lighting system with adequate switching facilities to give flexibility should be considered.

2.5 Daylighting

2.5.1

Making adequate use of natural light is one of the most important ways to reduce the building's energy load. Daylight is an efficient and economical light source - its cost being limited to the construction and maintenance of windows. It has additional advantages in that its provision can be combined with windows for natural ventilation and view; and it is generally preferred to artificial lighting because of its better colour rendition.

2.5.2

In designing a building for daylight, careful consideration should be given to the following factors:

(a) Glazing reduces the thermal performance of the wall. If necessary, the thermal performance of the glazing may need to be upgraded by installing sunshading devices and/or double glazing.

(b) The brightness of the source varies considerably from day to day and even from minute to minute. This may make it difficult to adjust internal light levels with artificial light. There may thus be a need for automatic switching or a "top-up" control system.

(c) Glare problems may be more difficult to deal with, as glare from daylight may come from several sources - direct sun, bright sky, external objects, sunlit translucent glazing panels, etc.

2.5.3

The quantity of daylight in an interior can be specified by the 'Daylight Factor' which is the ratio of the illuminance at a point inside to the illuminance on an unobstructed horizontal plane outside under a specified distribution of sky luminance, sunlight being excluded from both measurements.

2.5.4

Where meteorological data exist on the frequency of occurrence of different exterior illuminance from diffuse sky light (whether from cloud or sky, excluding direct sun-light), it is possible to use the daylight factor to predict the extent to which the required illuminances in interiors may be met by daylighting over the working hours in a year, and hence the average time in the year during which electric lighting must be used to supplement daylighting.

2.5.5

More information on this subject can be obtained from CIE Publication No 16 and BRE Digest 41 and 42 which describe various ways of predicting daylight factor at various points in a building from a given arrangement of windows or skylights and for given reflectances of interior surfaces.

2.5.6

Alternatively, the daylighting effect of a contemplated design can also be accurately predicted by a simulated study on its scale model.

2.6 Switching and Control

Energy used for lighting purposes is a product of the lighting load and the hours of use. Thus, individual switching of small groups is desirable to allow unnecessary lights to be switched off while permitting the others to be used. This will result in lower operating cost. It is suggested that as a good practice, the following points should be borne in mind in the design of switching to control lighting :-

(i) Lighting in task areas larger than 10m² shall be provided with controls so that the lighting can be reduced by at least half when the task is not performed or relocated.
(ii) Except for enclosed stairways and corridors used by the public, switches should be provided at accessible locations within sight of the light they control.
(iii) Where lighting switches are grouped, they should be suitably identified to indicate the area controlled by each switch.
(iv) Luminaires should be switched in row parallel to the windows, so that the rows of lights near to the windows can be turned off (manually or automatically) where daylighting is adequate.
(v) Where task lighting is installed, such lighting should be provided with switches located adjacent to the work station.
(vi) Multi-tube luminaires should be provided with multiple switching if appropriate.
(vii) Utilization of time-switches or photo-cell to control exterior lighting should be considered.

2.7 Management and Maintenance of Lighting

Below is a general checklist for the proper management and maintenance of lighting installation in order to maintain energy efficient operation.

(i) Turn off all lights when not needed.
(ii) Keep lamps and luminaires clean to maintain the required illumination level.
(iii) Replace lamps more frequently since lumen output drops with lamp ageing.
(iv) Use light colours for walls, ceiling, floor/carpets and curtains as this can reduce the amount of artificial lighting required.
(v) Reduce exterior lighting to the lowest level consistent with good security and safety.
(vi) Reduce or omit the use of outdoor lighting for decorative and advertising purposes.
(vii) Perform janitorial services earlier so that lights may be turned off earlier.
(viii) Consider replacing light sources with more efficient lamps;eg exchange incandescent with compact fluorescent lamps.

2.8 Lighting Load Requirements

2.8.1

In the building regulations, a set of lighting load requirements is laid down. These requirements, measured in watts per square metre, serve to limit the installed circuit wattage of the artificial lighting system in a space. In the case of a fluorescent lighting installation or other lighting installation requiring control gear, the circuit wattage shall include also the losses in the control gear. The building regulations require that the lighting load for the different types of occupancies shall not exceed the values given in the following table:-

Maximum Permissible Lighting Load

Type of Building	Maximum Lighting Load W/m²
Offices	20
Classrooms	20
Lecture Theatres, Auditoriums	25
Shops, Supermarkets, Departmental Stores	30
Restaurants	25
Lobbies, Corridors	10
Stairs	10
Car Parks	5

2.8.2

In general, the figures given in the table should be taken as an upper limit for the average lighting within the particular occupancy area or floor in question. But in the case of a shopping complex, the maximum lighting load will apply to each individual shop unit instead. To allow for the special needs of the stage and kitchen area in a restaurant, the lighting load requirement shall only be applied to the dining area and not the former. Similarly, the main entrance and the concourse of a building shall also be exempted from this requirement.

2.9 Submission Procedure

Where required by the Building Authority, the Professional Engineer responsible for the lighting installation should submit a complete set of plans showing the installed lighting devices and giving the following information to the Development & Building Control Division at the time of application for Certificate of Fitness:-

(i) The design standard service illuminance.
(ii) The number of each type of lighting device.
(iii) The total wattage of each type of lighting device, including nominal rating and gear losses.
(iv) The installed lighting load.

2.10 Other Reference

Reference should also be made to the Singapore Standard CP 24, Part 3 : Procedure for the Determination of Lighting Power Budget. Where the recommendations of this Handbook differ from those of the CP 24, the latter should take precedence over the former.

CHAPTER III AIR-CONDITIONING

3.1 General

Air conditioning accounts for the major portion of the total energy requirements for the operation of a typical commercial building. Air-conditioning system and equipment also constitute a very significant portion of the total capital outlay for such a project. Thus, if careful planning and due consideration is given to the design of the systems, substantial savings in both running cost and capital cost may be achieved.

3.2 Design Objectives and Considerations

3.2.1

Air-conditioning systems should be developed for optimum energy use. The selection process of air-conditioning systems should, wherever possible, include a quantitative evaluation of the annual energy usage. In the selection of equipment, both initial cost and life cycle cost should be considered.

3.2.2

Building load profile should be developed and analysed to enable engineering systems and equipment to be correctly sized and selected to give good efficiencies at maximum and part loads. Where practicable, the engineer should design modular systems with small units operating continuously at peak efficiency rather than one large unit operating at partial load most of the time.

3.2.3

The design of air-conditioning plant and associated automatic control systems should consider such factors as:-

(a) nature of the application;
(b) type of building construction;
(c) internal load patterns;
(d) desired space conditions;
(e) permissible control limits;
(f) use of suitable controls for minimising use of energy;
(g) use of heat recovery;
(h) economic considerations.

3.2.4

Systems should be selected to serve and control areas of similar load requirements. Smaller controlled areas achieve better controlled conditions when taking economic factors into account.

3.2.5

The temperature of the cooling media used should be at maximum values whilst still achieving the necessary heat exchange outputs.

3.2.6

Consideration should be given at the design stage to provide monitoring and control in order to achieve optimum operation with minimum consumption of fuel and energy. Adequate instrumentation for monitoring of energy use in building should be provided.

3.2.7

The cooling design loads for the purpose of sizing plant and systems should be determined in accordance with the procedure described in the latest edition of the ASHRAE Handbook of Fundamentals or other equivalent publications.

3.2.8

Systems that employ heating and cooling simultaneously in order to achieve comfort conditions shall not be used except where reclaimed energy can be used or except where alternative efficient methods of air-conditioning cannot be utilised to meet the system objectives.

3.2.9

Separate systems should be considered for serving areas of building with substantially different cooling load characteristics or operation patterns.

3.3 Control Systems

3.3.1

In general, the designer should aim at selecting a control system capable of maintaining thermal condition required. The degree of accuracy required of a control system should be compatible with the degree and nature of response of the plant or building.

3.3.2

Each system or zone should be provided with at least one temperature controlling device capable of being set between 20℃ and 30℃.

3.3.3

Each system should be equipped with readily accessible manual or automatic means of reducing the energy consumed for cooling during periods of non-use or reduced need.

3.3.4

Separate systems should be considered for serving areas with substantially different cooling characteristics. The building regulations specify that as a minimum, each floor of a large multi-level building shall be considered as a separate zone. Consideration should also be given to zone the east and west sections of the building separately to take account of the varying load profiles in a day.

3.3.5

A readily accessible manual or automatic means shall be provided to restrict or shut off cooling input to each floor or zone.

3.4 Indoor Conditions

The building regulations specify that the indoor conditions of an air-conditioned space shall be maintained within the following limits:-

(a) maximum dry bulb temperature 27℃
(b) minimum dry bulb temperature 23℃
(c) maximum relative humidity 75%
(d) maximum air movement 75 m/min

All these are measured at occupant level of 1.5m above floor.

3.5 Ventilation Rates

Unless exceptional circumstances require higher ventilation rates, the provision of outside air to air-conditioned space should not exceed by more than 30% of the following rates as specified in the building regulations:

Fresh Air Supply Requirement for Comfort Air-conditioning

Type of Building/Occupancy	Minimum Fresh Air Supply	
	m^3 /h per person	m^3 /h per m^2 of floor area
Restaurants & Dance Halls	17	10
Offices	13	1.2
Shops, Supermarkets & Departmental stores	13	2.3
Lobbies, Concourse & Corridors	13	0.9
Classrooms, Theatres & Cinemas	8.5	6.0
Factories & Workshops	13	1.8
Bedrooms & Apartments	13	--

3.6 Energy for Thermal Transport

3.6.1

The Air Transport Factor, as defined below, for each all-air system should not be less than 5.5.

$$\text{Air Transport Factor} = \frac{\text{Space Sensible Heat Removal}}{\text{Supply} + \text{Return Fans Power Input}}$$

III(1)

For constant volume systems, the factor should be based on design system air flow. For variable air volume systems, the factor may be based on average condition of operation.

3.6.2

The Water Transport Factor, as defined below, for chilled water should not be less than 30.

$$\text{Water Transport Factor} = \frac{\text{Sensible Heat Change in Chilled Water}}{\text{Circulating pumps power supply}}$$

III(2)

For constant volume systems, the factor should be based on design water flow. For variable pumping systems, the factor should be based on 75% of maximum design water flow.

3.7 Insulation of Pipes and Ducts

All chilled water pipes and air ducts should be properly insulated against heat gain from surrounding air. The acceptable insulation standards are:-

(i) Chilled Water Pipe

The insulation thickness for chilled water pipes should be as follows:-

Insulation Thickness for Chilled Water Pipe

Piping System Types	Fluid Temperature Range (ºC)	Insulation Thickness for Pipe Sizes					
		Round-out 50mm	**25mm and less**	**31mm to 50mm**	**63mm to 100mm**	**125 mm & 150mm**	**200mm and above**
Chilled Water Refrigerant or Brine	4.5 -13	1.3cm	1.3cm	1.9 cm	2.5 cm	2.5 cm	2.5 cm
	Below 4.5	2.5 cm	2.5 cm	3.8 cm	3.8 cm	3.8 cm	3.8 cm

The insulation thickness is based on insulation having thermal resistance in the range of 28 to 32m² ºK/W per metre of thickness on a flat surface at a mean temperature of 24°C. For material with thermal resistance greater than 32m² ºK/W per metre of thickness, the minimum insulation thickness is given by :

$$t = \frac{0.032 \times \text{Thickness in Table}}{\text{Actual R Value}}$$

III(3)

For material with thermal resistance less than 28m² ºK/W per metre of thickness, the minimum thickness should be:

$$t = \frac{0.028 \times \text{Thickness in Table}}{\text{Actual R Value}}$$

III(4)

(ii) Air Duct

The thermal resistance, excluding film resistance, should be:

$$R = \frac{\Delta t}{47.3} m^2 \, {}^\circ K/W$$

III(5)

where

Δt : design temperature differential between the air in the duct and the surrounding air in degree K.

3.8 Operation

The cooling systems in the parts of the building not in use should be turned off. There is little or no need at all to air-condition store rooms, entrances, toilets or staircases.

3.9 Maintenance

The owner should implement a preventive maintenance system and schedule periodic maintenance on all the critical items of an air-conditioning system such as compressors, cooling towers, pumps, condensers, air handlers, controls and filters.

3.10 Submission Procedure

Plans should be submitted to the Building Authority in accordance with the Building Control (Space, Light & Ventilation) Regulations.

The plans should contain the following information:

(i) The cooling capacity in kW of each air-handling unit and air-conditioning plant.
(ii) The capacity in m^3/h of each fan.
(iii) The location and capacity of each fresh air intake.
(iv) Supply, exhaust and return duct work distinctly coloured for clarity.
(v) A summary of air-conditioning load calculation, giving details of external and internal heat gain, the wall insulation and shading coefficients of windows assumed.

3.11 Other Reference

Reference should also be made to the Singapore Standard CP24, Part 1: Coefficient of Performance of Air-conditioning Equipment, and Part 2: Ventilation & Air-conditioning Systems. Where the recommendations of this Handbook differ from those of the CP24, the latter should take precedence over the former.

CHAPTER IV OVERALL THERMAL TRANSFER VALUE OF BUILDING ENVELOPE

Enter your keywords. (Mandatory)

4.1 Concept of OTTV

4.1.1

The solar heat gain through building envelope constitutes a substantial share of heat load in a building which will have to be eventually absorbed by the air-conditioning system at the expense of energy input. To minimise solar heat gain into a building is therefore the first and foremost consideration in the design of energy efficient building. The architectural techniques used to achieve such purpose are too numerous to mention. Siting and orientation of a rectangular building to avoid exposure of its long facades to face east and west, for instance, is a simple means of reducing solar heat gain if the building site permits. Appropriate choice of building shape to minimise building envelope area and selection of light colours for wall finish to reflect solar radiation are other common sense design alternatives to lower solar heat input.

4.1.2

In the building regulations, a design criterion for building envelope, known as the overall thermal transfer value (OTTV), has been adopted. The OTTV requirement, which applies only to air-conditioned buildings, is aimed at achieving the design of adequately insulated building envelope so as to cut down external heat gain and hence reduce the cooling load of the air-conditioning system. The OTTV concept takes into consideration the three basic elements of heat gain through the external walls of a building, viz. :

(a) heat conduction through opaque walls;
(b) heat conduction through glass windows;
(c) solar radiation through glass windows.

4.1.3

These three elements of heat input are averaged out over the whole envelope area of the building to give an overall thermal transfer value, or OTTV in short. This concept, in essence, helps to preserve a certain degree of flexibility in building design.

4.1.4

For the purpose of energy conservation, the maximum permissible OTTV has been set at 45 W/m^2 in the building regulations.

4.2 OTTV Formula for Envelope

4.2.1

To calculate the OTTV of an external wall, the following basic formula shall be used:

$$OTTV = \frac{(Aw \times Uw \times TDeq) + (Af \times Uf \times \Delta T) + (Af \times SC \times SF)}{Ao}$$

IV(1)

where,

OTTV : overall thermal transfer value (W/m^2)

Aw : opaque wall area (m^2)

Uw : thermal transmittance of opaque wall ($W/m^2\ ^oK$)

TDeq : equivalent temperature difference (^oK), see sub para 4.2.1.1

Af : fenestration area (m^2)

Uf : thermal transmittance of fenestration ($W/m^2\ ^oK$)

ΔT : temperature difference between exterior and interior

SC : shading coefficient of fenestration

SF : solar factor(W/m^2), see sub para 4.2.1.2

Ao : gross area of exterior wall (m^2)

$= Aw + Af$

4.2.1.1 Equivalent Temperature Difference

Equivalent Temperature Difference (TDeq) is that temperature difference which results in the total heat flow through a structure as caused by the combined effects of solar radiation and outdoor temperature. The TDeq across a structure takes into account the types of construction (mass and density), degree of exposure, time of day, location and orientation of the construction and design condition. By adopting the TDeq concept, the unsteady heat flow through a construction may then be calculated using the steady state heat flow equation:

$$q = A \times U \times TDeq$$

For the purpose of simplicity in OTTV calculation, the TDeq of different types of constructions have been narrowed down to three values according to the densities of the constructions, as given in the following table:

Equivalent Temperature Difference for Walls

Wall construction- Mass Per Unit Area	TDeq
0-125 kg/m²	15 ºK
126-195 kg/m²	12 ºK
above 195 kg/m²	10 ºK

4.2.1.2 Solar Factor

The Solar Factor for vertical surfaces has been experimentally determined for the Singapore climate. From data collected over a period of time for the eight primary orientations, the average Solar Factor for vertical surfaces has been worked out to be 130 W/m^2. This figure has to be modified by a correction factor when applied to a particular orientation and also if the fenestration component is sloped at an angle skyward. For the purpose of the building regulations, any construction having a slope angle of more than 70º with respect to the horizontal shall be treated as a wall. For a given orientation and angle of slope, the Solar Factor is to be calculated from the following formula:

$$SF = 130 \times CF (W/m^2)$$

Where CF is the correction factor with reference to the orientation of the facade and the pitch angle of the fenestration component and is given in the following table:

Slope Angle \ Orientation	N	NE	E	SE	S	SW	W	NW
70°	1.32	1.63	1.89	1.65	1.32	1.65	1.89	1.63
75°	1.17	1.48	1.75	1.50	1.18	1.50	1.75	1.48
80°	1.03	1.33	1.59	1.35	1.04	1.35	1.59	1.33
85°	0.87	1.17	1.42	1.19	0.89	1.19	1.42	1.17
90°	0.72	1.00	1.25	1.02	0.74	1.02	1.25	1.00

Solar Correction Factor for Wall

The correction factors for other orientations and other pitch angles may be found by interpolation.

4.2.2

As walls at different orientations receive different amounts of solar radiation, it is necessary in general to compute first the OTTVs of individual walls, then the OTTV of the whole building envelope is obtained by taking the weighted average of these values. To calculate the OTTV for the envelope of the whole building, the following formula shall be used:

$$OTTV = \frac{Ao_1 \times OTTV_1 + Ao_2 \times OTTV_2 + \cdots + Ao_n \times OTTV_n}{Ao_1 + Ao_2 + \cdots + Ao_n}$$

IV(3)

4.2.3

The gross area of an exterior wall shall include all opaque wall areas, window areas and door areas, where such surfaces are exposed to outdoor air and enclose an air-conditioned space. The fenestration area shall include glazing, glazing bars, mullions, jambs, transoms, heads and sills of window construction and shall be measured from the extreme surfaces of the window construction.

4.2.4

Where more than one type of material and/or fenestration is used, the respective term or terms shall be expanded into sub-elements, such as

$(Aw_1 \times Uw_1 \times TDeq_1) + (Aw_2 \times Uw_2 \times TDeq_2)$, etc.

4.2.5

For the purpose of OTTV calculation, the U-values of different components of the envelope construction shall be calculated in accordance with the method set out in Appendix I.

4.2.6

In the case where external sun-shading devices are used to shade the glass, the effective shading coefficients of such devices shall be determined in accordance with the method set out in Appendix II.

4.2.7

In the case of a mixed-use building where the residential portion and the commercial portion are distinctly and physically separated from each other, eg. in the form of a residential tower block and a commercial podium, the OTTVs of the two portions should be separately computed.

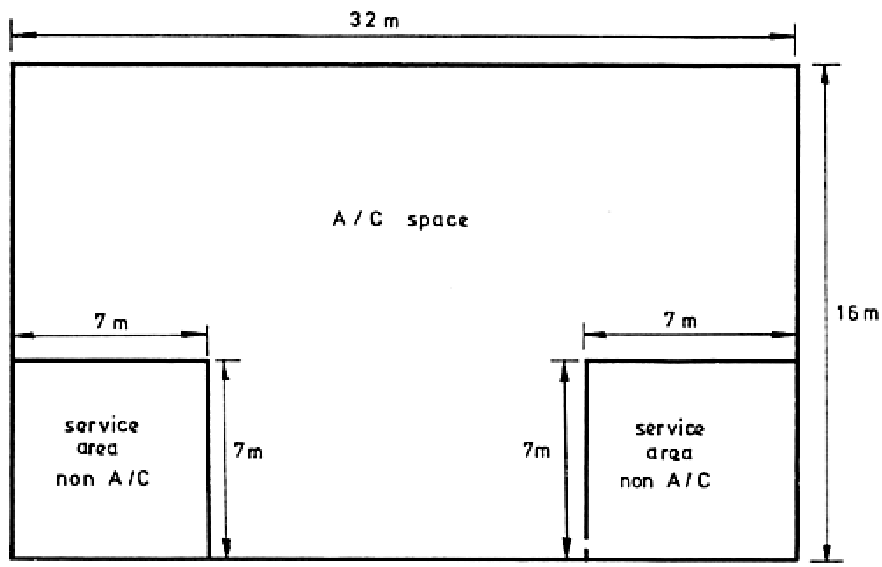
4.3 Submission Procedure

OTTV calculation for the building envelope shall be submitted by an architect or professional engineer in accordance with the prescribed Form of Submission. The calculation shall be forwarded to the Development & Building Control Division at the time of building plan submission.

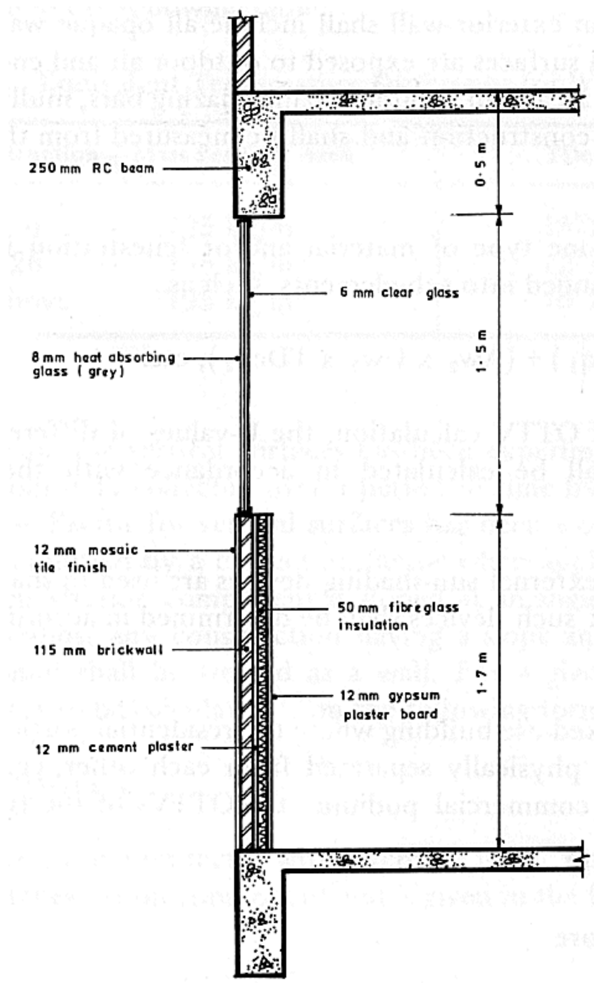
4.4 Example

To illustrate the method of calculating OTTV, an example is given here to highlight the steps taken in the calculation for a simple building. A further example is given in Appendix III to serve as a guide for OTTV submission.

4.4.1 Sketches



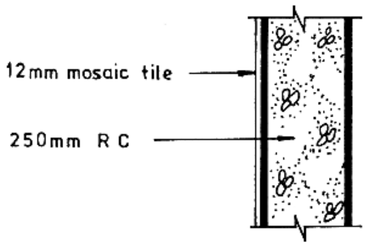
FLOOR PLAN



SECTIONAL DETAILS OF ENVELOPE

4.4.2 U-value Calculation

(a) For rc beam



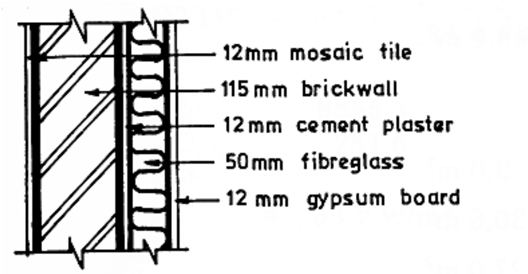
Component	b/k	R
outside air film		0.044
mosaic tile	0.012/ 1.298	0.009
rc	0.250/ 1.442	0.173
inside air film		0.120
Total R		0.346

$$U = \frac{1}{R} = \frac{1}{0.346} = 2.89\,W/m^2\,{}^{\circ}K$$

Weight = 2640 x 0.012 + 2400 x 0.25 = 632kg/m²

TDeq = 10ºK

(b) For brickwall



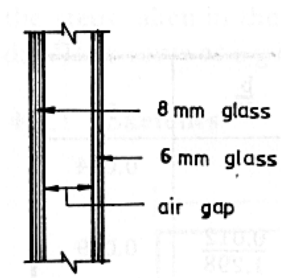
Component	b/k	R
outside air film		0.044
mosaic tile	0.012/ 1.298	0.009
brick wall	0.115/ 0.807	0.143
cement plaster	0.012/ 0.533	0.023
fibreglass	0.050/ 0.035	1.429
gypsum board	0.012/ 0.170	0.071
inside air film		0.120
Total R		1.839

$$U = \frac{1}{R} = \frac{1}{1.839} = 0.54W/m^2\,{}^\circ K$$

Weight = 2640 x 0.012 + 1760 x 0.115 + 1568 x 0.012 + 32 x 0.05 + 880 x 0.012 = 265kg/m²

TDeq = 10ºK

(c) For glass window



Component	b/k	R
outside air film		0.044
outer glass	0.008/ 1.053	0.008
air space		0.160
inner glass	0.006/ 1.053	0.006
inside air film		0.120
Total R		0.338

$$U = \frac{1}{R} = \frac{1}{0.338} = 2.96W/m^2\,{}^\circ K$$

SC = 0.5 (given)

4.4.3 Area Calculation

For North-facing wall

(a)	r.c. beam	Aw1	= 0.5 x 32	= 16.0m²
(b)	brickwall	Aw2	= 1.7 x 32	= 54.4m²
(c)	glass	Af	= 1.5 x 32	= 48.0m²

For South-facing wall

(a)	r.c. beam	Aw1	= 0.5 x 18	= 9.0m²
(b)	brickwall	Aw2	= 1.7 x 18	= 30.6m²
(c)	glass	Af	= 1.5 x 18	= 27.0m²

For East-facing wall

(a)	r.c. beam	Aw1	= 0.5 x 9	= 4.5m²
(b)	brickwall	Aw2	= 1.7 x 9	= 15.3m²
(c)	glass	Af	= 1.5 x 9	= 13.5m²

For West-facing wall

(Areas same as East-facing wall)

4.4.4 OTTV Calculation

For North-facing wall,

$$\left(SF = 130 \times 0.72\, W/m^2\right)$$

$$OTTV = \frac{(16 \times 2.89 \times 10) + (54.4 \times 0.54 \times 10) + 48(2.96 \times 5 + 0.5 \times 130 \times 0.72)}{16 + 54.4 + 48}$$

$$= \frac{3712.96}{118.4}$$

$$= 31.36\, W/m^2$$

For South-facing wall,

$$\left(SF = 130 \times 0.74\, W/m^2\right)$$

$$OTTV = \frac{(9 \times 2.89 \times 10) + (30.6 \times 0.54 \times 10) + 27(2.96 \times 5 + 0.5 \times 130 \times 0.74)}{9 + 30.6 + 2}$$

$$= \frac{2123.64}{66.6}$$

$$= 31.89\, W/m^2$$

For East & West-facing walls,

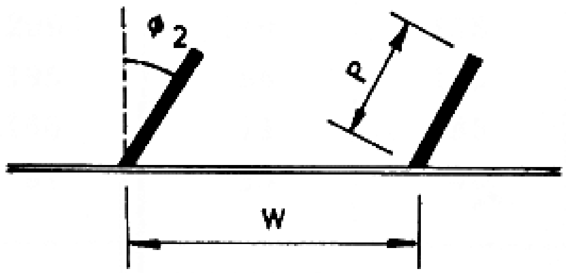
$$\left(SF = 130 \times 1.25\, W/m^2\right)$$

$$OTTV = \frac{(4.5 \times 2.89 \times 10) + (15.3 \times 0.54 \times 10) + 13.5(2.96 \times 5 + 0.5 \times 130 \times 1.25)}{4.5 + 15.3 + 13.5}$$

$$= \frac{1509.35}{33.3}$$

$$= 45.33\, W/m^2$$

For whole building,



$$OTTV = \frac{3712.96 + 2123.64 + 1509.35 + 1509.35}{118.4 + 66.6 + 33.3 + 33.3}$$

$$= \frac{8855.3}{251.6}$$

$$= 35.2 W/m^2$$

4.5 Weatherstripping of Windows and Doors

4.5.1

The concept of OTTV is based on the assumption that the envelope of the building is completely enclosed to minimise the infiltration of warm air and exfiltration of cool air. Infiltration and exfiltration contribute substantially to the building's heat gain as the warmer infiltrated air must be cooled in order to maintain the desired comfort condition.

4.5.2

As a basic requirement, the building must not have unenclosed doorways, entrances etc. For commercial buildings where heavy traffic of people is anticipated, self-closing doors should be provided.

4.5.3

To further minimise the exfiltration of cool air and infiltration of warm air through leaky windows and doors, effective means of weatherstripping should also be incorporated.

4.5.4

Preferably, doors and windows should be designed to meet the following criteria when tested under a pressure differential of 75 Pa:

(i) windows: leakage to limit to $2.77 m^3/h$ per metre of sash crack
(ii) swinging, revolving or sliding doors: leakage to limit to $61.2 m^3/h$ per linear metre of door crack

4.5.5

At building plan submission, the architect should endorse on plan the means of minimising air leakage and the performance envisaged of such measure. Report from recognised laboratory may be required.

CHAPTER V ROOF INSULATION AND ROOF OTTV

5.1 Thermal Transmittance of Roof

5.1.1

Solar heat gain into a building through an uninsulated roof increases air temperature indoor. In all buildings, directional radiation received on the roof can be one of the main causes of thermal discomfort.

5.1.2

For an air-conditioned building, solar heat gain through the roof also constitutes a substantial portion of the cooling load. From on-site solar radiation measurements taken in Singapore, the intensity of radiation on a horizontal surface can be as much as 3 times of that on a vertical surface.

The purpose of roof insulation is therefore two-folds: to conserve energy in air-conditioned buildings and to promote thermal comfort in non air-conditioned buildings, In both cases, the building regulations require that the roof shall not have a thermal transmittance or U-value greater than the values tabulated below:-

Maximum U-value for Roof

Weight Group	Weight Range(kg/m²)	Max Thermal Transmittance (W/m² ºK)	
		Air-conditioned Building	Non air-conditioned Building
Light	Under 50	0.5	0.8
Medium	50 to 230	0.8	1.1
Heavy	Over 230	1.2	1.5

5.1.3

The U-value of a roof shall be calculated in accordance with the method set out in Appendix I.

5.1.4

Where more than one type of roof is used, the average thermal transmittance for the gross area of the roof should be determined from:

$$Ur = \frac{Ar_1 \times Ur_1 + Ar_2 \times Ur_2 + \cdots + Ar_n \times Ur_n}{Ar_1 + Ar_2 + \cdots + Ar_n} \qquad V(1)$$

where,

Ur : the average thermal transmittance of the gross roof area (W/m² ºK)

Ur1, Urn : the respective thermal transmittance of different roof sections (W/m² ºK)

Ar1, Arn : the respective area of different roof sections (m²)

Similarly, the average weight of the roof should be calculated as follows:

$$Wr = \frac{Ar_1 \times Wr_1 + Ar_2 \times Wr_2 + \cdots + Ar_n \times Wr_n}{Ar_1 + Ar_2 + \cdots + Ar_n} \qquad V(2)$$

where,

Wr : average weight of roof (kg/m^2)

Wr_1, Wr_n : the respective weight of different roof sections (kg/m^2)

5.2. OTTV of Roof

5.2.1

In the case of air-conditioned building, the concept of overall thermal transfer value, or OTTV, is also applicable to its roof if the latter is provided with skylight. The OTTV concept for roof takes into consideration three basic elements of heat gain, viz.:

(a) heat conduction through opaque roof;
(b) heat conduction through skylight;
(c) solar radiation through skylight.

The maximum permissible OTTV for roofs is set at 45 W/m^2 which is the same as that for walls.

5.2.2

To calculate the OTTV of a roof, the following basic formula shall be used:-

$$OTTV = \frac{(Ar \times Ur \times TDeq) + (As \times Us \times \Delta T) + (As \times SC \times SF)}{Ao}$$

V(3)

where,

OTTV : overall thermal transfer value (W/m^2)

Ar : opaque roof area (m^2)

Ur : thermal transmittance of opaque roof area (W/m^2 ºK)

TDeq : equivalent temperature difference (” K), see sub-para 5.2.2.1

As : skylight area (m^2)

Us : thermal transmittance of skylight area (W/m^2 ºK)

$\triangle$T : temperature difference between exterior and interior design conditions (5ºK)

SC : shading coefficient of skylight

SF : solar factor (W/m^2), see sub-para 5.2.2.2

Ao : gross area of roof (m^2) = Ar + As

5.2.2.1 Equivalent Temperature Difference

For the purpose of simplicity in OTTV calculation, the TDeq of different types of roof constructions have been standardised as follows:-

Equivalent Temperature Difference for Roof

Roof Construction--Mass Per Unit Area	TDeq
0--50kg/m²	24ºK
50--230kg/m²	20ºk
Over--230kg/m²	16ºk

5.2.2.2 Solar Factor

For a given orientation and angle of slope, the Solar Factor is given by:

$$SF = 320 \times CF\left(W/m^2\right)$$

V(4)

where CF is the correction factor with reference to the orientation of the roof and the pitch angle of its skylight and is given as follows:-

Slope Angle \ Orientation	N	NE	E	SE	S	SW	W	NW
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5°	1.00	1.01	1.02	1.02	1.00	1.02	1.02	1.01
10°	1.01	1.03	1.04	1.03	1.01	1.03	1.04	1.03
15°	1.01	1.03	1.05	1.03	1.01	1.03	1.05	1.03
20°	1.00	1.03	1.06	1.03	1.01	1.03	1.06	1.03
25°	0.98	1.02	1.06	1.03	0.99	1.03	1.06	1.02
30°	0.96	1.01	1.05	1.01	0.97	1.01	1.05	1.01
35°	0.93	0.98	1.03	0.99	0.94	0.99	1.03	0.98
40°	0.90	0.96	1.01	0.96	0.91	0.96	1.01	0.96
45°	0.86	0.92	0.98	0.92	0.87	0.93	0.98	0.92
50°	0.81	0.89	0.95	0.89	0.83	0.89	0.95	0.89
55°	0.77	0.84	0.91	0.85	0.78	0.85	0.91	0.84
60°	0.71	0.79	0.86	0.80	0.73	0.80	0.86	0.79
65°	0.66	0.74	0.81	0.75	0.67	0.75	0.81	0.74

Solar Correction Factor for Roof

The Correction Factors for other orientations and other pitch angles may be found by interpolation.

For the purpose of the building regulations, any construction with a pitch angle less than 70º shall be treated as a roof.

5.2.3

If a roof consists of different sections facing different orientations or pitched at different angles, the OTTV for the whole roof shall be calculated as follows:-

$$OTTV = \frac{Ao_1 \times OTTV_1 + Ao_2 \times OTTV_2 + \cdots + Ao_n \times OTTV_n}{Ao_1 + Ao_2 + \cdots + Ao_n}$$

V(5)

5.2.4

The gross area of a roof shall include all opaque roof areas and skylight areas, when such surfaces are exposed to outdoor air and enclose an air-conditioned space.

5.2.5.

When more than one type of material and/or skylight is used, the respective term or terms shall be expanded into sub-elements as:

$$(Ar_1 \times Ur_1 \times TDeq_1) + (Ar_2 \times Ur_2 \times TDeq_2) + \ldots$$

5.2.6

The OTTV requirement for roof applies to an air-conditioned building and is over and above the U-value requirement.

5.2.7

The OTTV of the roof should not be computed together with that of the walls. Each component should be treated separately.

5.3 Submission Procedure

At the time of submission of building plans, the architect should provide the information on roof insulation by:-

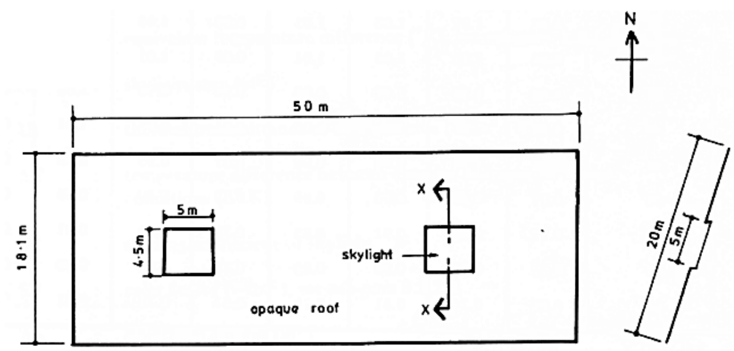
(i) submitting a drawing showing the cross sections of typical parts of the roof construction, giving details of the type and thickness of basic construction materials, insulation and air space;

(ii) calculating the U-value of the roof assembly according to Appendix I; and

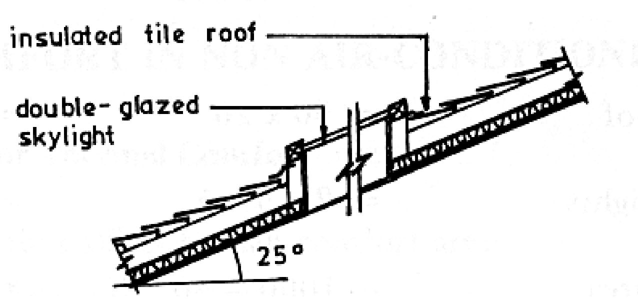
(iii) if the building is air-conditioned, calculating the OTTV of the roof assembly.

5.4 Example

5.4.1 Sketches



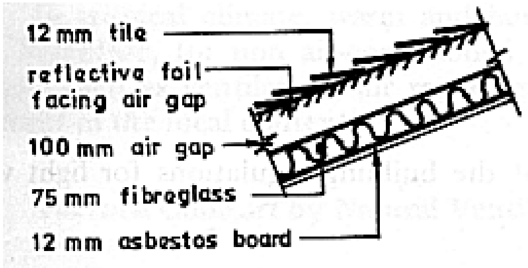
PLAN VIEW OF ROOF



SECTION X- X

5.4.2. U-value Calculation

(a) For Opaque Roof



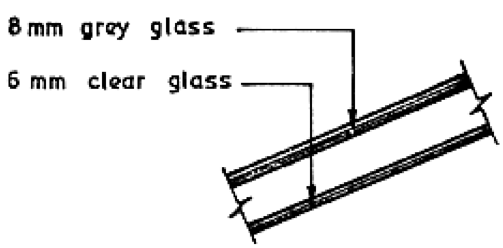
Component	b/k	R
outside air film		0.055
roof tile	0.012/ 0.836	0.014
reflective foil		
air space (low E)		1.095
fibreglass	0.075/ 0.035	2.143
asbestos board	0.012/ 0.108	0.111
inside air film		0.148
Total R		**3.566**

$$U = \frac{1}{R} = \frac{1}{3.566} = 0.28 W/m^2 \, ^\circ K$$

Weight = 1890 x 0.012 + 32 x 0.075 + 720 x 0.012 = 33.7kg/m²

TDeq = 24ºK

(b) For skylight



Component	b/k	R
outside air film		0.055
glass	0.008/ 1.053	0.008
air space (high E)		0.165
glass	0.006/ 1.053	0.006
inside air film		0.148
Total R		**0.382**

$$U = \frac{1}{R} = \frac{1}{0.382} = 2.62 W/m^2 \, ^\circ K$$

SC = 0.5 (given)

Weight = 2512 x 0.008 + 2512 x 0.006 = 35.2kg/m²

5.4.3 Area Calculation

Area of whole roof	= 50 x 20	= 1000m²
Area of two skylights	= 2 x 5 x 5	= 50m²
Area of opaque area	= 1000 - 50	= 950m²

5.4.4 Weighted Average Weight of Roof

Since both roof components belong to the light weight group, the combined roof also belongs to the light weight group.

5.4.5 Weighted Average U-value

$$U = \frac{0.28 \times 950 + 2.62 \times 50}{1000} = 0.4W/m^2 \,{}^\circ K$$

This satisfies the U-value requirement of the building regulations for light weight roof.

5.4.6 Roof OTTV

For north orientation at 25º pitch, SF = 320 x 0.98W/m²

$$OTTV = \frac{950 \times 0.28 \times 24 + 50(2.62 \times 5 + 0.5 \times 320 \times 0.98)}{1000} = \frac{14879}{1000} = 14.88W/m^2$$

This also satisfies the OTTV requirement for roof.

CHAPTER VI THERMAL COMFORT IN NON AIR-CONDITIONED BUILDING

6.1 General Principles of Thermal Comfort

6.1.1

The main variables that affect human comfort are:-

(a) dry bulb temperature;
(b) wet bulb temperature (relative humidity);
(c) air movement; and
(d) thermal radiation from hot surfaces.

To a lesser extent, certain other factors also affect human comfort; these are atmospheric pressure, ion concentration, etc. The combined effects of the various factors have been investigated and comfort scales and indices have been developed.

6.1.2

In tropical climate, warm and humid conditions prevail during most parts of the year. Therefore, for non air-conditioned buildings, the control of these factors affecting comfort, such as ventilation, air movement and radiation from ceiling and walls, are very important in the local context.

6.2 Thermal Comfort by Natural Ventilation

6.2.1

Apart from meeting physiological needs, ventilation also serves to provide a thermally comfortable indoor environment by removing indoor heat gain from various sources. The formula which relates ventilation rate to indoor temperature build-up is given as follows:-

$$Q = \frac{q}{p\, Cp\left(\theta_2 - \theta_1\right)} \qquad \text{VI(1)}$$

where

Q : ventilation rate

q : total heat gain from occupants, power driven equipment, light fitting and structural heat gain

p : average air density

Cp : specific heat of air

θ_2-θ_1 : total temperature rise of incoming air

6.2.2

As a general rule, ventilation rate of 2.8m^3/min to 5.7 m^3/min per person is adequate in practice if the average indoor air temperature rise of not more than ½℃ is to be maintained as a result of body heat. Where power-driven equipment and other heat sources are present, a higher ventilation rate is necessary.

6.3 Natural Ventilation by Window Opening

6.3.1

The influence of the size of windows on the internal air movement depends to a great extent on whether the room is cross-ventilated. If the window is located on one wall of a room, its size will have little effect on the internal air velocity. However, an even distribution of windows and the correct choice of sashes will help to improve the ventilation even when the windows are located on one wall.

6.3.2

When cross ventilation in a room is assured, the relationship between ventilation rate and design wind speed is govern by the following equation:

$$Q = 17 \; Ce \; VA \tag{VI(2)}$$

where

Q : ventilation rate in m^3 /min

Ce : combined coefficient of discharge for the number and spacing of openings in series (the values of Ce are taken to be 0.47 and 0.43, depending on whether there are only two or three sets of ventilation openings in series)

V : design wind speed in km/h

A : area of opening in m^2

6.3.3

The design wind speed for a particular type of structure, locality and orientation has to be duly corrected to allow for height and screening effects of other buildings. The coefficient of discharge Ce is found to decrease fairly rapidly with an increase in the distance between the two openings in series, i.e. with an increase in room width. At 5.5m, it will level off to about 0.47. In equation VI(2), Ce is used to modify the external wind speed. A 16-year record of wind speed in Singapore is reproduced in Appendix IV.

To determine the wind velocity near a building, the wind available at the time and height of the building, as well as the velocity gradient due to the ground friction, must be considered.

The wind speed recorded by the Singapore Meteorological Services (Appendix IV) can be assumed to be in an open country and is a reduced speed of the free stream at some distance above the height at which this speed is measured. A general equation, known as the 'Power Law' is given by equation VI(3):

$$Vz = Vg\left(\frac{Z}{Zg}\right)^{a} \tag{VI(3)}$$

where

Vz : velocity at height z

Vg : gradient velocity

Z : height

Zg : gradient height

a : a power index as given in the following table

Values of ‘a’

Type of Country	Zg (metre)	a
Open country	274	0.16
Moderately rough, wooded country, small town	396	0.28
Rough, centre of large town	518	0.4

6.4 Natural Ventilation by Jack Roof and Roof Ventilator

6.4.1

The performance of roof ventilators is normally rated in terms of wind speed and indoor and outdoor temperature differential to take into account the two natural motive forces of ventilation: thermal force and wind effect. In the Singapore context, the thermal effect is negligible and the primary motive force of ventilation is due to wind effect. The performance of roof cowls can be rated in the simplified equation as follows:

$$Q = 208\ AV \qquad \text{VI(4)}$$

where

Q : ventilation rate (m^3/h)

A : throat area of ventilator (cm^2)

V : wind speed (km/h)

6.4.2

For jack roof, the performance is poorer than that of roof cowl and there is no quantitative assessment of jack roof. However, assuming that jack roofs are about 50% as efficient as cowl ventilators since the windward side of a jack roof does not act as exhaust opening, it has been worked out that the nett area of opening of jack roofs required per metre run of a building is about $1.2m^2$ for a building width of 18m.

6.4.3

Jack roof or roof ventilator should not be situated more than 9m from other jack roof or roof ventilator. For jack roof, a minimum nett area of $1.2m^2$ per metre run of jack roof is necessary and for roof cowl ventilator, design should be substantiated by anticipated performance based on manufacturer’s data or calculated from formula VI (4).

6.5 Provisions for Natural Ventilation and Lighting

6.5.1

In the building regulations, it is specified that every building shall be provided with:-

(a) natural lighting by means of windows, skylights, fan-lights, doors, and other approved natural light transmitting media; and

(b) natural ventilation by means of windows, skylights, fanlights, doors, louvres or similar ventilation openings.

6.5.2

In general, openings facing the sky, street, courtyard or airwell will be considered as acceptable sources of natural lighting and ventilation.

6.5.3

In the case of a building other than factory or godown, any part of the building within 9m from an acceptable opening shall be deemed to be adequately lighted and ventilated by natural means.

6.5.4

In the case of a factory or godown, the maximum effective coverage of any window and other opening on an external wall shall be deemed to be 12m from the opening, whereas the coverage of any jack roof or other opening on the roof shall be deemed to be 9m measured horizontally from the opening.

6.5.5

In addition, the building regulations also specify that every room in any building shall be provided with natural lighting and ventilation by means of one or more sources having an aggregate area of not less than x percent of the floor space of the room, of which at least y percent shall have opening to allow free uninterrupted passage of air. The respective values of x and y are given in the following table according to the types of occupancy or types of usage of the room.

Size of Opening for Natural Lighting & Ventilation.

Type of Occupancy or Usage of Room	x% of Floor Area of Room	y% of x openable
Residential	15%	50%
Store, Utility, Garage(in residential premises)	10%	50%
Water-closet, Toilet, Bathroom, Laundry	10% or $0.2m^2$(whichever is greater)	100%
Business	15%	50%
School classroom	20%	50%
Hospital, Nursing home	15%	100%
Lobby, Corridor, Staircase	10%	50%
Godown	10%	50%

6.5.6

In the case of public garages, two or more sides of the garage shall have opening for cross ventilation and the area of opening shall be at least 50% of the area of the wall where it is located.

6.5.7

For terrace houses having a depth greater than 12m, permanent ventilation from front to rear shall be provided to facilitate cross ventilation by suitable vents in all front, back and cross walls at each floor. Such vents shall have a nett opening area of not less than $0.4m^2$ each.

6.6 Mechanical Ventilation

6.6.1

Where site conditions dictate that the normal requirements for natural lighting and ventilation cannot be met, the building regulations may allow the use of mechanical ventilation as a substitute.

6.6.2

According to the building regulations, the quantity of fresh air supply for mechanical ventilation of any room or space in a building shall be in accordance with the specified rates in the following table:-

Fresh Air Supply for Mechanical Ventilation

	Minimum Fresh Air Supply	
Type of Building/Occupancy	**Air Change Per Hour**	**m^3/h per person**
Office	6	18
Restaurant, Canteen	6	18
Shop, Supermarket, Departmental Store	6	18
Workshop, Factory	6	18
Classroom, Theatre, Cinema	8	-
Lobby, Concourse, Corridor, Staircase	4	-
Toilet, Bathroom	10	-
Kitchen(commercial, institutional & industrial)	20	-
Car Park	6	-

Unless justified by exceptional circumstances, the ventilation rate shall not be exceeded by more than 30%

6.7 Thermal Insulation

6.7.1

The effects of directional radiation from uninsulated roof and the statutory requirement on roof insulation have been discussed and covered in Chapter V of this Handbook. It suffices to mention here that the purpose of insulating the roof in a non air-conditioned building is to lower the total heat gain through the roof.

6.7.2

Besides roof insulation, the building regulations also specify that in the case of a non air-conditioned building any external wall abutting a habitable room shall have a U-value of not more than 3.5 $W/m^2\ {}^{o}K$.

6.8 Sun-shading

6.8.1

To encourage the provision of sun-shading devices in residential building for the purpose of improving thermal comfort, the building regulations make a special provision to relax the requirement pertaining to boundary clearance. Where overhangs, canopies, awnings or other sun-shading devices are provided, these devices are permitted to project up to a point not less than 1600mm from the lot boundary instead of the normal requirement of 2300mm for boundary clearance.

6.8.2

To take advantage of this relaxation, architect should ensure that only non-combustible materials are used for the construction of the shading devices.

6.8.3

It should be noted that the relaxation is only in respect of the projection of the shading devices, whereas the walls from which such devices project shall comply with the normal boundary clearance requirement.

APPENDIX I U-VALUE CALCULATION

1 Thermophysical Properties of Building Materials

1.1 Thermal conductivity (K-value)

The ability of a material to transmit heat is measured by its thermal conductivity or K-value. The K-value of a material is defined as the quantity of heat transmitted under steady-state conditions through unit area of the material of unit thickness in unit time when unit temperature difference exists between its opposite surfaces. It is expressed in W/m ºK.

Table I(1) gives the K-values of some commonly used building materials.

1.2 Thermal Resistivity (r)

The thermal resistivity of a material is the reciprocal of its thermal conductivity, i.e.

$$r = \frac{1}{K}$$

It may be defined as the time required for one unit of heat to pass through unit area of a material of unit thickness when unit temperature difference exists between opposite faces. It is expressed as m ºK/W.

1.3 Thermal Conductance (C)

Thermal conductance refers to specific thickness of a material or construction. It is the thermal transmission through unit area of a material per unit temperature difference between the hot and cold faces. It is expressed in W/m² ºK and is given by:

$$C = \frac{K}{b}$$

where

b: thickness of the material

1.4 Thermal Resistance (R)

The thermal resistance of a material or construction is the reciprocal of its thermal conductance. It refers to the thermal resistance of any section or assembly of building components and is particularly useful in computing the overall transfer of heat across the building section. It is expressed as m² ºK/W and is given by:

$$R = \frac{1}{C} = \frac{b}{K}$$

2 Thermal Transmittance (U-value)

2.1 The thermal transmittance or U-value of a construction is defined as the quantity of heat that flows through a unit area of a building section under steady-state conditions in unit time per unit temperature difference of the air on either side of the section. It is expressed in W/m² ºK and is given by:

$$U = \frac{1}{R_T}$$

where R_T is the total thermal resistance and is given by:

$$R_T = Ro + \frac{b_1}{K_1} + \frac{b_2}{K_2} + \cdots + \frac{b_n}{K_n} + Ri$$

where

Ro : air film resistance of external surface (m² ºK/W)

Ri : air film resistance of internal surface (m² ºK/W)

K : thermal conductivity of basic material (W/m ºK)

b : thickness of basic material (m)

3 Surface Air Film Resistance

3.1 The transfer of heat to and from a surface of a body through air is impeded by the presence of a thin layer of relatively motionless air at the surface of the body. This offers resistance to the heat flow and results in a temperature drop across the layer of air.

3.2 Surface air film resistance is affected by wind velocity and therefore different resistance values for outside and inside air films are given. These are defined as follow:-

Ro -outside surface air film resistance (moving air)

Ri -inside surface air film resistance (still air)

3.3 Table I(2) gives the values of surface resistances for walls and roofs at different positions of surface and for different surface emissivities. The effect of emissivity on the thermal resistance of an air layer will be discussed in the next section.

4 Air Space Resistance

4.1 Air is a relatively poor conductor of heat. Its presence as a gap between two layers of materials contributes further thermal resistance to the whole construction. The U-value of a building section can therefore be modified as follows:-

$$U = \frac{1}{R_T}$$

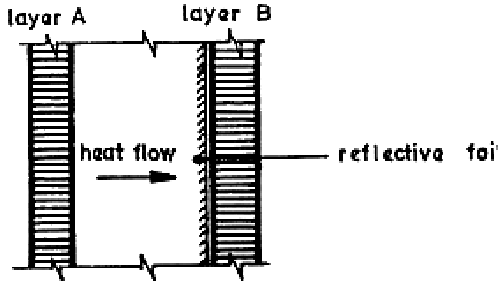
and

$$R_T = Ro + \frac{b_1}{K_1} + \cdots Ra + \cdots + \frac{b_n}{K_n} + Ri$$

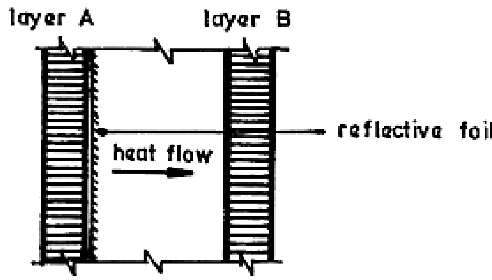
where

Ra : thermal resistance of air space

4.2 Reflective materials such as aluminium foil have high surface reflectivity and low surface emissivity. If a reflective foil is inserted in an air space with its reflective surface facing the space and against the direction of heat flow as shown below, approximately 95% of the radiation will be reflected. This increases the thermal resistance of the air space.



4.3 If the heat flow is reversed as shown below, the result would be the same as in this case, the low emissivity of the reflective surface emits only about 5% of the absorbed heat as radiant energy.



4.4 Table I(3) gives the values of air space resistances for walls and roofs at different positions and for different surface emissivities in the air space.

TABLE I(1) K-VALUES OF BASIC MATERIALS

Sr. No.	Material		Density kg/m³	K-value W/m ºK
1	Asbestos cement sheet		1488	0.317
2	Asbestos insulating board		720	0.108
3	Asphalt, roofing		2240	1.226
4	Bitumen			1.298
5	Brick:	(a) dry (covered by plaster or tiles outside)	1760	0.807
		(b) common brickwall(brickwall directly exposed to weather outside)		1.154
6	Concrete		2400	1.442
			64	0.144
7	Concrete, light weight		960	0.303
			1120	0.346
			1280	0.476
8	Cork board		144	0.042
9	Fibre board		264	0.052
10	Fibre glass(see Glass Wool and Mineral Wool)			
11	Glass, sheet		2512	1.053
12	Glass wool, mat or guilt (dry)		32	0.035
13	Gypsum plaster board		880	0.170
14	Hard board:	(a) standard	1024	0.216
		(b) medium	640	0.123
15	Metals:	(a) Aluminium alloy, typical	2672	211
		(b) copper, commercial	8784	385
		(c) Steel	7840	47.6
16	Mineral wool, felt		32-104	0.035-0.032
17	Plaster	(a) gypsum	1216	0.370
		(b) perlite	616	0.115
		(c) sand/cement	1568	0.533
		(d) vermiculite	640-960	0.202-0.303
18	Polystyrene, expanded		16	0.035
19	Polyurethane, foam		24	0.024
20	PVC flooring		1360	0.713
21	Soil, loosely packed		1200	0.375
22	Stone, tile:	(a) sand stone	2000	1.298
		(b) granite	2640	2.927
		(c) marble/terrazzo/ceramic/ mosaic	2640	1.298
23	Tile, roof		1890	0.836
24	Timber:	(a) across grain softwood	608	0.125
		(b) hardwood	702	0.138
		(c) plywood	528	0.138
25	Vermiculite, loose granules		80-112	0.065
26	Wood chipboard		800	0.144
27	Woodwool slab		400	0.086
			480	0.101

TABLE I(2) Surface Film Resistances for Walls and Roofs

Type of Surface					Thermal Resistance m² ºK/W
A.	Surface Film Resistances for Walls	1 Inside surface (Ri)	(a) High Emissivity		0.120
			(b) Low Emissivity		0.299
		2 Outside surface (Ro)	(High Emissivity)		0.044
B.	Surface Film Resistances for Roofs	1 Inside surface (Ri)	(a) High Emissivity	(i) Flat roof	0.162
				(ii) Sloped roof 22½º	0.148
				(iii) Sloped roof 45º	0.133
			(b) Low Emissivity	(i) Flat roof	0.801
				(ii) Sloped roof 22½º	0.595
				(iii) Sloped roof 45º	0.391
		2 Outside surface (Ro) (High Emissivity)		Flat or sloped	0.055

Note:
1) Ordinarily, high emissivity is assumed for surfaces of building materials with reasonably smooth finishing. Low emissivity applies only to internal surface if the surface is very reflective, such as that of an aluminium foil.
2) Interpolation between the angle of slope from horizontal to 45º is permitted. For angle beyond 45º, the value for 45º can be used, no extrapolation is needed.

TABLE I(3) Air Space Resistances for Walls and Roofs

Type of Air Space			Thermal Resistance m² ºK/W		
			5mm	20 mm	100 mm
A Air Space Resistances (Ra) for Walls Vertical air space (Heat flows horizontally)		(a) High Emissivity	0.110	0.148	0.160
		(b) Low Emissivity	0.250	0.578	0.606
B Air Space Resistances (Ra) for Roofs Horizontal or sloping air space (Heat flows downward)	(a) High Emissivity	(i) horizontal air space	0.110	0.148	0.174
		(ii) sloped air space 22½º	0.110	0.148	0.165
		(iii) sloped air space 45º	0.110	0.148	0.158
	(b) Low Emissivity	(i) horizontal air space	0.250	0.572	1.423
		(ii) sloped air space 22½º	0.250	0.571	1.095
		(iii) sloped air space 45º	0.250	0.570	0.768
C Attic Space Resistances (R attic)		(a) High Emissivity	0.458		
		(b) Low Emissivity	1.356		

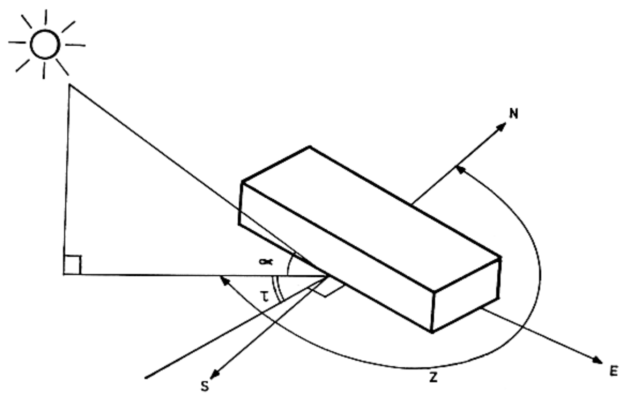
Note:
1) Ordinarily, high emissivity is assumed for air spaces bounded by building materials of moderately smooth surfaces. Low emissivity only applies where one or both sides of the air space is bounded by a reflective surface such as that of an aluminium foil.
2) Interpolation within the range of pitch angles from horizontal to 45º is permitted. For angle beyond 45º, the value for 45º can be used; no extrapolation is needed.
3) Interpolation within the range of thickness from 5mm to 100mm is permitted. For air space less than 5mm, extrapolation basing on Ra = 0 for zero thickness is allowed; otherwise Ra is assumed to be zero. For air space greater than 100mm, the Ra for 100mm should be used, i.e. extrapolation is not permitted.
4) In the case of air space in roof, reflective foil used should be installed with the reflective surface facing downward as dust deposit will render an upward-facing surface ineffective after a while.

APPENDIX II SHADING COEFFICIENT OF EXTERNAL SUN SHADING DEVICES

1 Basic Solar Data

1.1 Solar Geometry

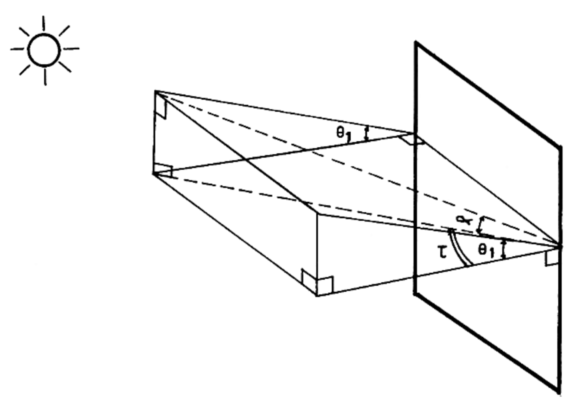
The position of the sun can be specified by the angles illustrated below:



These angles are (i) altitude (α, angle above the horizon) and (ii) azimuth (z, compass orientation of a vertical plane through the sun, measured clockwise from north). The orientation of a wall is the angle measured clockwise from north of a plane normal to the wall, and the wall-solar azimuth (τ) is the angle between the two planes.

1.2 Shadow Angles

For the purpose of finding the shading effect of horizontal projections, fins, louvres, or canopies, the vertical shadow angle (VSA) is required. This is the angle (θ_1) between two planes viz, the horizontal plane and an inclined plane projected through the sun as illustrated in the diagram below:



The vertical shadow angle is given by:

$$\tan \theta_1 = \tan \alpha \sec \tau$$

where

θ_1 : the vertical shadow angle

α : the altitude of the sun

τ : the wall-solar azimuth

To calculate shading coefficient of vertical fins and projections, the horizontal shadow angle (HSA) has to be determined and it is given by the wall-solar azimuth angle , i.e.

$$\theta_2 = \tau$$

where

θ_2 : the horizontal shadow angle

1.3 Intensity of Solar Radiation

To facilitate the calculation of effective shading coefficient of external shading devices, the intensities of diffuse, direct and total radiation transmitted through a standard 3mm clear glass sheet are tabulated in Table II(1) to II(4) together with the horizontal and vertical shadow angles for March, June, September and December.

2 Shading Coefficient

2.1 Basic Concept

In the OTTV formula, the solar factor has been derived from the annual average of solar radiation transmitted through a 3mm clear glass window. For other system of fenestration, the rate of solar heat gain is modified by the shading coefficient of the fenestration system which is defined as the ratio of solar heat gain through the fenestration system having combination of glazing and shading device to the solar heat gain through an unshaded 3mm clear glass. This ratio is a unique characteristic of each type of fenestration system and is represented by the equation:

$$SC = \frac{\text{Solar heat gain of any glass and shading combination}}{\text{Solar heat gain through a 3mm unshaded clear glass}}$$

In general, the shading coefficient of any fenestration system can be obtained by multiplying the shading coefficient of the glass and the effective shading coefficient of the external sun-shading device as follows:

$$SC = SC_1 \times SC_2$$

where

SC : shading coefficient of the fenestration system

SC_1 : shading coefficient of glass

SC_2 : effective shading coefficient of external shading devices

(Note:
For the purpose of OTTV calculation, the shading effect offered by internal Venetian blind and curtain should be ignored.)

The shading coefficient of glass should be based on the manufacturer's recommended value assessed at an incident angle of 45º to the normal.

The effective shading coefficient of external shading devices as given in Tables II(5) to II(16) shall be used unless the type of shading device in question is not included in the Tables. In that case, the effective shading coefficient shall be calculated from the basic solar data given in Tables II(1) to II(4) in accordance with the method specified in Section 2.2.

2.2 Method of Calculating Effective Shading Coefficient of External Sun-Shading Device

2.2.1 When a window is partially shaded by an external shading device, it is assumed that the exposed portion receives the total radiation, I_T, and the shaded portion receives only the diffuse radiation, Id.

The instantaneous heat gain due to solar radiation can then be expressed as follows:

$Q = Ae \times I_T + As \times Id = Ae \times I_D + (Ae + As) \times Id$

where

Q	: solar heat gain
Ae	: exposed area of window
As	: shaded area of window
I_T	: total radiation
I_D	: direct radiation
Id	: diffuse radiation

since

$A = Ae + As$

$Q = Ae \times I_D + A \times I_d$

For an unshaded 3mm clear glass, the solar heat gain is given by $A \times I_T$. By definition, the Hourly Shading Coefficient, SC, of a shading device can be expressed as:

$$SC = \frac{Ae \times I_D + A \times Id}{A \times I_T} = \frac{G \times I_D + Id}{I_T}$$

where

$$G = \frac{Ae}{A}$$

the fraction of area exposed to direct solar radiation

2.2.2 To calculate the shading coefficient (SC) of a shading device for the whole day, the hourly solar heat gain shall be computed and summed up for the 12 day-light hours. The total solar heat gain is then divided by the sum of the total radiation, I_T, through an unshaded 3mm clear glass for the same hours of the day, to obtain the SC for the day. Mathematically, the computation can be expressed as follows:-

$$SC_d = \frac{\sum_{h=1}^{h=12} \left(Ae \times I_D + A \times Id\right)_h}{\sum_{h=1}^{h=12} \left(A \times I_T\right)_h}$$

where subscript d and h refers to daily & hourly respectively.

2.2.3 For simplicity, the SC of a shading device for a particular month can be worked out basing on the solar data for a representative day of the month.

2.2.4 To determine the effective SC of a shading device, theoretically, the computation has to be carried out for 12 months of the year. However, as the computation involved is rather tedious and the degree of accuracy required is not a critical factor, it is deemed sufficient to base the SC computation on 4 representative months of the year, viz March, June, September and December. The representative days of these 4 months are March 21, June 22, September 23 and December 22.

2.2.5 Further, since the solar data for March 21 and September 23 are almost identical, if suffices to compute the solar heat gain for March and double it to take account of the heat gain for September. Mathematically, the effective SC of a shading device is given by:-

$$\text{Effective SC} = \frac{\sum_M (G \times I_D + Id) + \sum_J (G \times I_D + Id) + \sum_S (G \times I_D + Id) + \sum_D (G \times I_D + Id)}{\sum_M I_T + \sum_J I_T + \sum_S I_T + \sum_D I_T}$$

where

M denotes March

J denotes June

S denotes September

D denotes December

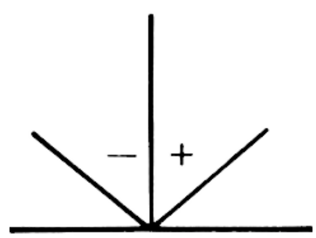
2.2.6 The relevant solar data are given in Tables II(1) to II(4).

2.3 Determination of 'G' Factor

The fraction of window area exposed to the sun (G) at any time for a given orientation can be determined using solar geometry. With the VSA and HSA given, the G factor can be worked out graphically. For simple design, the G factor can also be calculated using plane trigonometry. In the following examples of calculating the G factor for simple horizontal overhangs, vertical fins and egg-crate sun-shades using trigonometry, the following convention is used:-

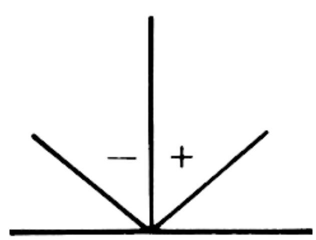
θ_1 = VSA (always positive)

θ_2 = HSA (positive, if to the right of wall orientation;
negative, if to the left of wall orientation).

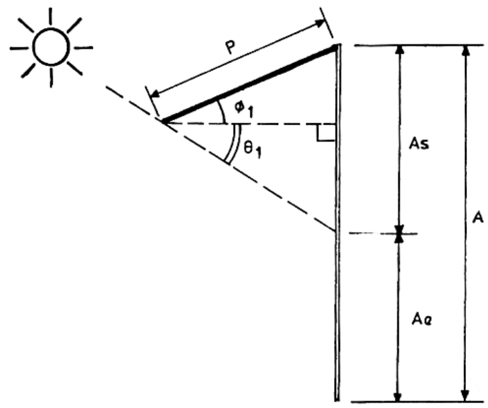


ϕ_1 = projection angle of horizontal projections with respect to horizontal plane (assumed positive for practical reason).

ϕ_2 = projection angle of vertical fin with respect to wall orientation (positive, if to the right of wall orientation; negative, if to the left of wall orientation).



2.3.1 For continuous horizontal projection fixed at window head level.



$$As = P\ Cos\,\phi_1 \tan\theta_1 + P\ Sin\,\phi_1 = P\left(Cos\,\phi_1 \tan\theta_1 + Sin\,\phi_1\right)$$

$$Ae = A - As$$

$$\frac{Ae}{A} = 1 - \frac{P}{A}\left(Cos\,\phi_1 \tan\theta_1 + Sin\,\phi_1\right)$$

or

$$G_1 = 1 - R_1\left(Cos\,\phi_1 \tan\theta_1 + Sin\,\phi_1\right)$$

where

$$G_1 = \frac{Ae}{A}$$

and

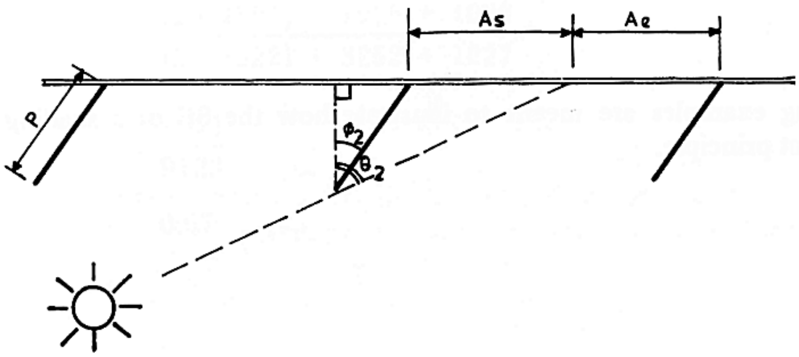
$$R_1 = \frac{P}{A}$$ for horizontal projections

Note:

$$G_1 \geq 0$$

Table II(5) to Table II(8) give the SC of horizontal projections for a range of R_1 value with θ_1 ranging from 0º to 50º.

2.3.2 For continuous vertical fins in an array.



$$As = \left|P\ Cos\phi_2 \tan\theta_2 - P\ Sin\ \phi_2\right|$$
$$= P\left|Cos\phi_2 \tan\theta_2 - Sin\ \phi_2\right|$$

$$Ae = A - As$$

$$\frac{Ae}{A} = 1 - \frac{P}{A}\left|Cos\phi_2 \tan\theta_2 - Sin\ \phi_2\right|$$

or

$$G_2 = 1 - R_2\left|Cos\phi_2 \tan\theta_2 - Sin\ \phi_2\right|$$

where

$$G_2 = \frac{Ae}{A}$$

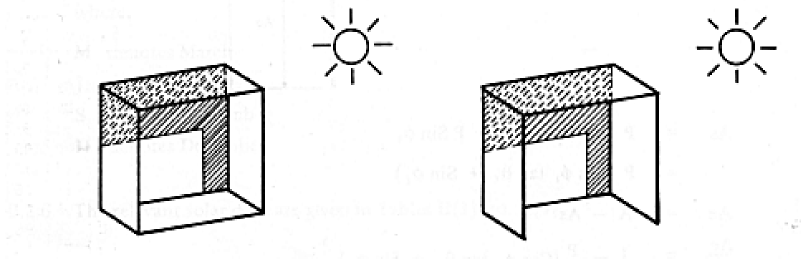
and

$$R_2 = \frac{P}{A}$$ for vertical fins

Note: $G_2 \geq 0$

Table II(9) to Table II(12) give the SC of vertical fins for a range of R_2 values with $|\theta_2|$ ranging from 0º to 50º. θ_2 is chosen for the situation which gives the lower SC of the two possible values, viz positive or negative θ_2.

2.3.3 For egg-crate and combination fins made up of horizontal and vertical components for which the horizontal component may be sloped.



$G_1 = 1 - R_1(\text{Cos}\,\phi_1 \tan\theta_1 + \text{Sin}\,\phi_1)$

Since G_1 and G_2 are independent of each other, the combined effect of the two components can be expressed as follows:-

$$G_3 = G_1 \times G_2$$

Note:

$$G_3 \geq 0$$

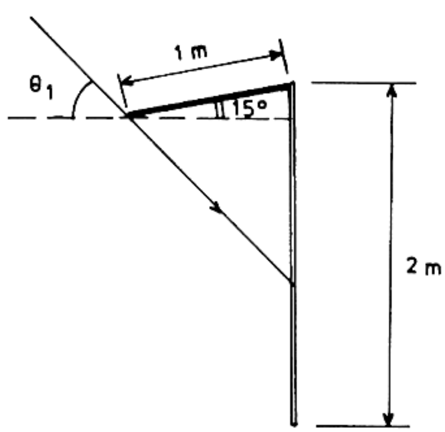
Table II(13) to Table II(16) give the SC of combination fins for a range of R_1 and R_2 values with θ_1 ranging from 0º to 40º.

2.4 Example

The following examples are meant to illustrate how the SC of a shading device is calculated from first principle.

2.4.1 Example A

Find the effective shading coefficient of a sloping horizontal projection 1m in length, inclined at 15º and located over a window of 2m in height, in a North-East facing direction.



ϕ_1 = 15º

R_1 = ½ = 0.5

NE	March21 / September23					June22					December22				
item	θ_1	(1-G)	I_D	Id	Q	θ_1	(1-G)	I_D	Id	Q	θ_1	(1-G)	I_D	Id	Q
7am	6	0.180	94	23	100	6	0.180	159	33	163	15	0.260	52	20	58
8am	26	0.365	293	76	262	21	0.315	387	86	351	46	0.630	111	63	104
9am	44	0.600	336	106	240	34	0.455	462	116	368	67	-	87	83	83
10 am	59	0.933	278	126	144	47	0.647	435	133	286	81	-	28	98	98
11 am	72	-	154	136	136	58	0.902	345	141	175	-	-	0	109	109
12 noon	83	-	31	136	136	68	-	216	141	141	-	-	0	116	116
1pm	-	-	0	133	136	78	-	98	110	110	-	-	0	116	116
2pm	-	-	0	123	123	88	-	29	116	116	-	-	0	108	108
3pm	-	-	0	104	104	-	-	0	93	93	-	-	0	93	93
4pm	-	-	0	85	85	-	-	0	76	76	-	-	0	73	73
5pm	-	-	0	60	60	-	-	0	53	53	-	-	0	50	50
6pm	-	-	0	28	28	-	-	0	23	23	-	-	0	20	20
$\sum Q=\sum(G\times I_D+Id)$			1554					1955					1028		
$\sum I_T=\sum(I_D+Id)$			2322					3252					1227		
SC (day)			0.669					0.601					0.838		

Effective SC (Annual)

$$= \frac{2\times\sum_M(G\times I_D+Id)+\sum_J(G\times I_D+Id)+\sum_D(G\times I_D+Id)}{2\times\sum_M(I_T)+\sum_J(I_T)+\sum_D(I_T)}$$

$$= \frac{(2\times1554)+1955+1028}{(2\times2322)+3252+1227} = \frac{6091}{9123} = 0.67$$

2.4.2 Example B

Find the effective SC value of an egg-crate shading device having $R_1 = 0.4$, $\phi_1 = 0$, $R_2 = 0.4$ in the North-facing direction.

June 22								
item	θ_1	G_1	θ_2	G_2	G_3	I_D	Id	Q
7am	15	0.893	67	0.058	0.05	60	25	28
8am	41	0.652	65	0.142	0.093	145	63	76
9am	55	0.429	63	0.215	0.092	187	91	108
10 am	62	0.248	57	0.384	0.095	208	114	134
11 am	66	0.102	45	0.60	0.061	219	131	144
12 noon	68	0.01	21	0.846	0	222	141	141
1pm	68	0.01	-14	0.90	0	225	141	141
2pm	66	0.102	-41	0.652	0.067	219	134	149
3pm	63	0.215	-55	0.429	0.092	209	119	138
4pm	57	0.384	-62	0.248	0.095	195	98	116
5pm	44	0.614	-65	0.142	0.087	156	71	85
6pm	21	0.847	-66	0.102	0.086	81	33	40

$$\Sigma Q = \Sigma[(G_3 \times I_D) + Id] = 1300$$

$$\Sigma(I_T) = 3287$$

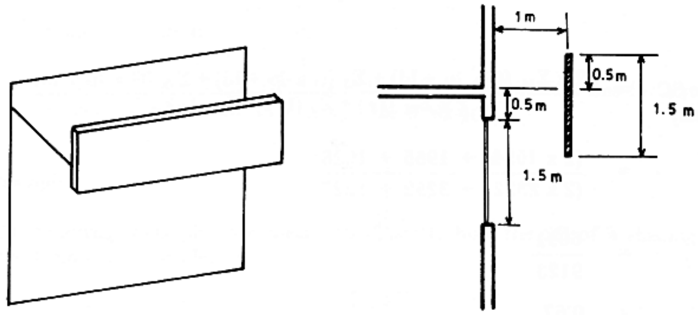
Therefore SC (June 22) $= \dfrac{1300}{3287}$

$$= 0.395$$

The same procedure is repeated for March 21/ September 23 in order to work out the effective SC for the whole year.

2.4.3 Example C

Find the effective SC of the shading device shown in the diagram below. It is installed in the North-facing wall.



Fig(a)

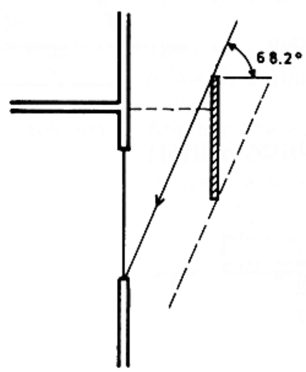
The glass window is shaded by a panel parallel to the wall. The shadow cast on the window varies according to the time of the day depending on the sun's position and its vertical shadow angle (θ_1).

For $68.2^\circ<\theta_1<90^\circ$, the shading device is ineffective as sun rays strike the window directly without being obstructed. Hence, the shading coefficient is taken as 1. See figure (b).

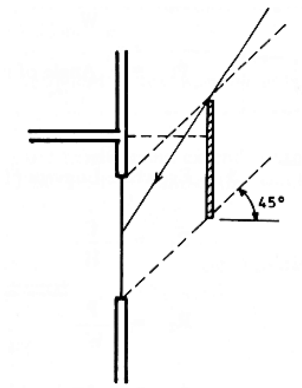
For $45^\circ<\theta_1<68.2^\circ$, the window is partially shaded by the upper portion of the strip. See figure (c). For $\theta_1=45^\circ$, the window is totally shaded.

For $\theta_1<45^\circ$, the window is also partially shaded by the lower portion of the strip. See figure (d).

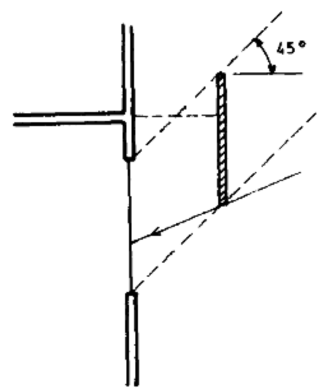
The shadow patterns for figure (c) and figure (d) can be worked out by simple geometry.



Fig(b)



Fig(c)



Fig(d)

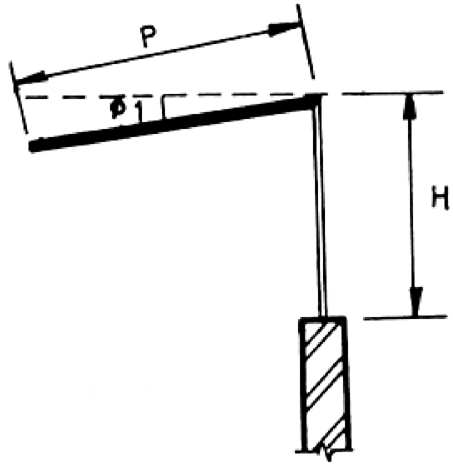
2.5 Tables of Effective Shading Coefficient of External Shading Devices

2.5.1 Keys:

1 Horizontal Projections (Tables II(5) to II(8))

$$R_1 = \frac{P}{H}$$

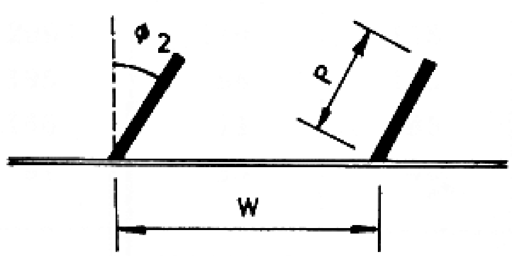
ϕ_1 = Angle of inclination



2 Vertical Projections (Tables II(9) to II(12))

$$R_2 = \frac{P}{W}$$

ϕ_2 = Angle of inclination



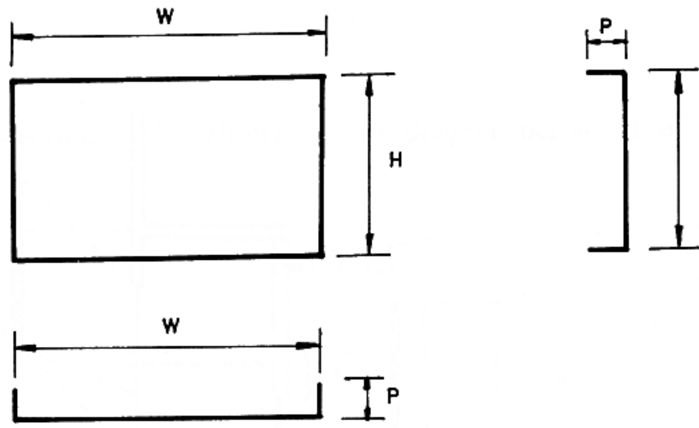
3 Egg-crate Louvres (Tables II(13) to II(16))

$$R_1 = \frac{P}{H}$$

$$R_2 = \frac{P}{W}$$

ϕ_1 = Angle of inclination

$$R_1 = \frac{P}{H}$$



$$R_2 = \frac{P}{W}$$

2.5.2 Examples

1

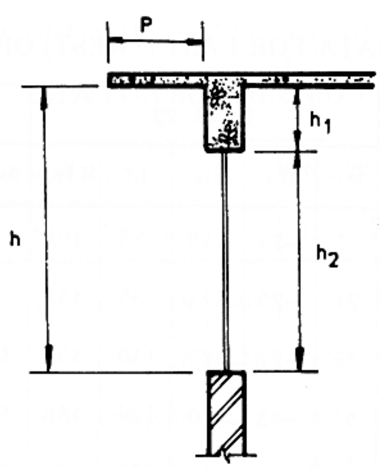
Given	:	Window on South-West facing wall with a 0.3m horizontal overhang.
Find	:	The effective shading coefficient if (a) height of window is 0.6m (b) height of window is 0.75m with the overhang inclined at 30º to the horizontal.
Solution	:	Refer to Table II(8)
		a) $R_1 = 0.5$ SC =0.698
		b) $R_1 = 0.4$ SC =0.669

2

Given : Window on West facing wall with a 0.3m horizontal overhang and the height of window is 0.75m.

Find : The effective shading coefficient if the window is located 0.2m below the overhang.

Solution : Assuming the window has a height h and extends to the underside of the overhang, the solar heat gain into the window can be expressed as follows:



$$SC.h = SC_1.h_1 + SC_2.h_2$$

From Table II(6) by interpolation

SC = 0.8123, h = 950 (R_1 = 0.32)

SC_1 = 0.5051 , h_1 = 200 (R_1 = 1.5)

$$SC_2 = \frac{SC.h - SC_1.h_1}{h_2}$$

SC_2 =0.894

TABLE II (1): SOLAR DATA FOR NORTH (*SOUTH) ORIENTATION

TIME	March21 / September23					June22					December22				
	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T
7am	90	+90	0	13	13	15	+67	60	25	85	-	-	0	15	15
8am	90	+90	0	48	48	41	+65	145	63	208	-	-	0	48	48
9am	-	-	0	76	76	55	+63	187	91	278	-	-	0	71	71
10 am	-	-	0	98	98	62	+57	208	114	322	-	-	0	91	91
11 am	-	-	0	118	118	66	+45	219	131	350	-	-	0	109	109
12 noon	-	-	4	129	133	68	+21	222	141	363	-	-	0	117	117
1pm	-	-	0	133	133	68	-14	225	141	366	-	-	0	116	116
2pm	-	-	0	123	123	66	-41	219	134	353	-	-	0	108	108
3pm	-	-	0	104	104	63	-55	209	119	328	-	-	0	93	93
4pm	-	-	0	85	85	57	-62	195	98	293	-	-	0	73	73
5pm	90	-90	0	60	60	44	-65	156	71	227	-	-	0	50	50
6pm	90	-90	0	28	28	21	-66	33	81	144	-	-	0	20	20

Note:
*For the purpose of calculating shading coefficient, the Solar Data for the North orientation can be used for the South orientation.

TABLE II(2): SOLAR DATA FOR EAST (*WEST) ORIENTATION

TIME	March21 / September23					June22					December22				
	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T
7am	4	+0	136	25	161	7	-23	159	33	192	6	+24	159	30	189
8am	19	+0	429	88	517	21	-25	374	83	457	21	+25	394	86	480
9am	34	+1	504	121	625	36	-27	427	110	537	36	+29	445	114	559
10 am	49	+2	435	139	574	51	-33	360	126	486	51	+36	373	129	502
11 am	64	+3	282	146	428	66	-45	213	131	344	67	+49	216	134	350
12 noon	79	+7	74	141	215	81	-69	44	126	170	82	+73	41	126	167
1pm	-	-	0	133	133	-	-	0	116	116	-	-	0	116	116
2pm	-	-	0	123	123	-	-	0	109	109	-	-	0	108	108
3pm	-	-	0	104	104	-	-	0	93	93	-	-	0	93	93
4pm	-	-	0	85	85	-	-	0	76	76	-	-	0	73	73
5pm	-	-	0	60	60	-	-	0	53	53	-	-	0	50	50
6pm	-	-	0	28	28	-	-	0	23	23	-	-	0	20	20

Note:
*For the purpose of calculating shading coefficient, the Solar Data for the East orientation can be used for the West orientation.

TABLE II(3): SOLAR DATA FOR NORTH-EAST (*NORTH-WEST) ORIENTATION

TIME	March21 / September23					June22					December22				
	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T
7am	6	+45	94	23	117	6	+22	159	33	192	15	+69	52	20	72
8am	26	+45	293	76	369	21	+20	387	86	473	46	+70	111	63	174
9am	44	+46	336	106	442	34	+18	462	116	578	67	+74	87	83	170
10 am	59	+47	278	126	404	47	+12	435	133	568	81	+81	28	98	126
11 am	72	+48	154	136	290	58	-0	345	141	486	-	-	0	109	109
12 noon	83	+52	31	136	167	68	-24	216	141	357	-	-	0	116	116
1pm	-	-	0	133	133	78	-59	98	110	208	-	-	0	116	116
2pm	-	-	0	123	123	88	-86	29	116	145	-	-	0	108	108
3pm	-	-	0	104	104	-	-	0	93	93	-	-	0	93	93
4pm	-	-	0	85	85	-	-	0	76	76	-	-	0	73	73
5pm	-	-	0	60	60	-	-	0	53	53	-	-	0	50	50
6pm	-	-	0	28	28	-	-	0	23	23	-	-	0	20	20

Note:
*For the purpose of calculating shading coefficient, the Solar Data for the North-East orientation can be used for the North-West orientation.

TABLE II(4): SOLAR DATA FOR SOUTH-EAST (*SOUTH-WEST) ORIENTATION

TIME	March21 / September23					June22					December22				
	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T	θ_1	θ_2	I_D	Id	I_T
7am	6	-45	94	23	117	16	-68	53	23	76	6	-21	162	30	192
8am	26	-45	321	48	369	46	-70	114	63	177	20	-20	417	88	505
9am	44	-44	382	76	458	65	-72	97	86	183	34	-16	496	119	615
10 am	58	-43	325	98	423	79	-78	38	98	136	46	-9	470	136	606
11 am	70	-42	180	136	316	-	-	0	106	106	57	+4	389	146	535
12 noon	82	-38	47	139	186	-	-	0	116	116	67	+28	244	144	388
1pm	-	-	0	133	133	-	-	0	116	116	76	+60	99	131	230
2pm	-	-	0	123	123	-	-	0	109	109	86	+84	9	111	120
3pm	-	-	0	104	104	-	-	0	93	93	-	-	0	93	93
4pm	-	-	0	85	85	-	-	0	76	76	-	-	0	73	73
5pm	-	-	0	60	60	-	-	0	53	53	-	-	0	50	50
6pm	-	-	0	28	28	-	-	0	23	23	-	-	0	20	20

Note:
*For the purpose of calculating shading coefficient, the solar data for the South-East orientation can be used for the South-West orientation.

TABLE II (5) : EFFECTIVE SHADING COEFFICIENTS OF HORIZONTAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS.

ORIENTATION : NORTH & SOUTH						
R_1	0º	10º	20º	30º	40º	50º
0.1	0.9380	0.9330	0.9300	0.9291	0.9303	0.9336
0.2	0.8773	0.8674	0.8613	0.8595	0.8619	0.8685
0.3	0.8167	0.8017	0.7927	0.7899	0.7935	0.8033
0.4	0.7560	0.7392	0.7288	0.7245	0.7263	0.7382
0.5	0.7210	0.7080	0.7001	0.6950	0.6927	0.6938
0.6	0.7041	0.6921	0.6848	0.6804	0.6774	0.6760
0.7	0.6923	0.6842	0.6775	0.6723	0.6689	0.6672
0.8	0.6871	0.6779	0.6702	0.6661	0.6641	0.6626
0.9	0.6819	0.6718	0.6670	0.6643	0.6621	0.6604
1.0	0.6767	0.6690	0.6655	0.6625	0.6600	0.6583
1.1	0.6731	0.6678	0.6640	0.6607	0.6584	0.6577
1.2	0.6713	0.6667	0.6625	0.6589	0.6577	0.6577
1.3	0.6705	0.6656	0.6611	0.6582	0.6577	0.6577
1.4	0.6698	0.6644	0.6596	0.6577	0.6577	0.6577
1.5	0.6690	0.6633	0.6588	0.6577	0.6577	0.6577
1.6	0.6683	0.6622	0.6582	0.6577	0.6577	0.6577
1.7	0.6675	0.6610	0.6577	0.6577	0.6577	0.6577
1.8	0.6667	0.6599	0.6577	0.6577	0.6577	0.6577
1.9	0.6660	0.6594	0.6577	0.6577	0.6577	0.6577
2.0	0.6652	0.6589	0.6577	0.6577	0.6577	0.6577
2.1	0.6645	0.6585	0.6577	0.6577	0.6577	0.6577
2.2	0.6637	0.6581	0.6577	0.6577	0.6577	0.6577
2.3	0.6630	0.6577	0.6577	0.6577	0.6577	0.6577
2.4	0.6622	0.6577	0.6577	0.6577	0.6577	0.6577
2.5	0.6614	0.6577	0.6577	0.6577	0.6577	0.6577
2.6	0.6607	0.6577	0.6577	0.6577	0.6577	0.6577
2.7	0.6604	0.6577	0.6577	0.6577	0.6577	0.6577
2.8	0.6601	0.6577	0.6577	0.6577	0.6577	0.6577
2.9	0.6599	0.6577	0.6577	0.6577	0.6577	0.6577
3.0	0.6596	0.6577	0.6577	0.6577	0.6577	0.6577

TABLE II (6) : EFFECTIVE SHADING COEFFICIENTS OF HORIZONTAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS.

ORIENTATION : EAST & WEST						
R_1	0º	10º	20º	30º	40º	50º
0.1	0.9363	0.9268	0.9195	0.9147	0.9124	0.9129
0.2	0.8752	0.8565	0.8416	0.8309	0.8257	0.8257
0.3	0.8228	0.7947	0.7723	0.7563	0.7470	0.7448
0.4	0.7703	0.7330	0.7036	0.6820	0.6693	0.6664
0.5	0.7248	0.6842	0.6500	0.6231	0.6045	0.5946
0.6	0.6911	0.6424	0.6013	0.5691	0.5467	0.5349
0.7	0.6574	0.6006	0.5559	0.5249	0.5012	0.4851
0.8	0.6237	0.5693	0.5273	0.4923	0.4651	0.4467
0.9	0.5998	0.5463	0.4991	0.4608	0.4389	0.4237
1.0	0.5827	0.5232	0.4727	0.4442	0.4222	0.4062
1.1	0.5656	0.5002	0.4587	0.4296	0.4075	0.4010
1.2	0.5485	0.4828	0.4468	0.4151	0.4036	0.3969
1.3	0.5314	0.4739	0.4349	0.4089	0.3999	0.3963
1.4	0.5156	0.4650	0.4230	0.4059	0.3969	0.3963
1.5	0.5051	0.4561	0.4147	0.4029	0.3963	0.3963
1.6	0.4995	0.4472	0.4123	0.3999	0.3963	0.3963
1.7	0.4939	0.4383	0.4101	0.3974	0.3963	0.3963
1.8	0.4882	0.4294	0.4079	0.3963	0.3963	0.3963
1.9	0.4826	0.4237	0.4057	0.3963	0.3963	0.3963
2.0	0.4770	0.4204	0.4035	0.3963	0.3963	0.3963
2.1	0.4713	0.4190	0.4013	0.3963	0.3963	0.3963
2.2	0.4657	0.4176	0.3991	0.3963	0.3963	0.3963
2.3	0.4601	0.4163	0.3978	0.3963	0.3963	0.3963
2.4	0.4544	0.4149	0.3968	0.3963	0.3963	0.3963
2.5	0.4488	0.4135	0.3963	0.3963	0.3963	0.3963
2.6	0.4432	0.4122	0.3963	0.3963	0.3963	0.3963
2.7	0.4400	0.4108	0.3963	0.3963	0.3963	0.3963
2.8	0.4369	0.4094	0.3963	0.3963	0.3963	0.3963
2.9	0.4339	0.4081	0.3963	0.3963	0.3963	0.3963
3.0	0.4333	0.4067	0.3963	0.3963	0.3963	0.3963

TABLE II (7): EFFECTIVE SHADING COEFFICIENTS OF HORIZONTAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS.

ORIENTATION : NORTH-EAST & NORTH-WEST						
R_1	0º	10º	20º	30º	40º	50º
0.1	0.9273	0.9193	0.9137	0.9106	0.9101	0.9122
0.2	0.8630	0.8471	0.8355	0.8285	0.8263	0.8291
0.3	0.8054	0.7820	0.7644	0.7533	0.7489	0.7515
0.4	0.7563	0.7278	0.7055	0.6895	0.6803	0.6799
0.5	0.7171	0.6824	0.6546	0.6345	0.6228	0.6198
0.6	0.6787	0.6443	0.6165	0.5946	0.5793	0.5710
0.7	0.6549	0.6166	0.5842	0.5587	0.5420	0.5320
0.8	0.6327	0.5889	0.5563	0.5360	0.5200	0.5088
0.9	0.6105	0.5681	0.5412	0.5184	0.5026	0.4919
1.0	0.5922	0.5560	0.5261	0.5051	0.4900	0.4826
1.1	0.5809	0.5440	0.5148	0.4939	0.4840	0.4790
1.2	0.5722	0.5321	0.5046	0.4877	0.4809	0.4759
1.3	0.5634	0.5243	0.4971	0.4850	0.4782	0.4759
1.4	0.5547	0.5165	0.4921	0.4825	0.4759	0.4759
1.5	0.5466	0.5086	0.4894	0.4802	0.4759	0.4759
1.6	0.5413	0.5037	0.4874	0.4780	0.4759	0.4759
1.7	0.5359	0.5001	0.4854	0.4759	0.4759	0.4759
1.8	0.5306	0.4965	0.4837	0.4759	0.4759	0.4759
1.9	0.5253	0.4949	0.4821	0.4759	0.4759	0.4759
2.0	0.5200	0.4936	0.4804	0.4759	0.4759	0.4759
2.1	0.5162	0.4923	0.4787	0.4759	0.4759	0.4759
2.2	0.5141	0.4909	0.4770	0.4759	0.4759	0.4759
2.3	0.5119	0.4897	0.4759	0.4759	0.4759	0.4759
2.4	0.5097	0.4886	0.4759	0.4759	0.4759	0.4759
2.5	0.5075	0.4876	0.4759	0.4759	0.4759	0.4759
2.6	0.5053	0.4865	0.4759	0.4759	0.4759	0.4759
2.7	0.5047	0.4855	0.4759	0.4759	0.4759	0.4759
2.8	0.5042	0.4844	0.4759	0.4759	0.4759	0.4759
2.9	0.5036	0.4834	0.4759	0.4759	0.4759	0.4759
3.0	0.5031	0.4823	0.4759	0.4759	0.4759	0.4759

TABLE II (8) :EFFECTIVE SHADING COEFFICIENTS OF HORIZONTAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS.

ORIENTATION : SOUTH-EAST & SOUTH-WEST						
R_1	0º	10º	20º	30º	40º	50º
0.1	0.9253	0.9167	0.9107	0.9072	0.9065	0.9086
0.2	0.8574	0.8405	0.8280	0.8203	0.8177	0.8204
0.3	0.7964	0.7715	0.7527	0.7406	0.7355	0.7377
0.4	0.7413	0.7100	0.6862	0.6692	0.6601	0.6597
0.5	0.6981	0.6615	0.6321	0.6109	0.5985	0.5951
0.6	0.6578	0.6179	0.5890	0.5663	0.5503	0.5417
0.7	0.6289	0.5891	0.5555	0.5289	0.5107	0.5004
0.8	0.6059	0.5604	0.5251	0.5044	0.4880	0.4765
0.9	0.5828	0.5372	0.5096	0.4863	0.4702	0.4592
1.0	0.5619	0.5248	0.4942	0.4727	0.4573	0.4493
1.1	0.5502	0.5124	0.4826	0.4613	0.4507	0.4459
1.2	0.5413	0.5003	0.4722	0.4551	0.4477	0.4429
1.3	0.5323	0.4923	0.4646	0.4516	0.4451	0.4429
1.4	0.5234	0.4843	0.4596	0.4492	0.4429	0.4429
1.5	0.5150	0.4763	0.4558	0.4471	0.4429	0.4429
1.6	0.5096	0.4714	0.4538	0.4449	0.4429	0.4429
1.7	0.5042	0.4678	0.4521	0.4429	0.4429	0.4429
1.8	0.4988	0.4642	0.4505	0.4429	0.4429	0.4429
1.9	0.4933	0.4610	0.4489	0.4429	0.4429	0.4429
2.0	0.4879	0.4598	0.4472	0.4429	0.4429	0.4429
2.1	0.4841	0.4585	0.4456	0.4429	0.4429	0.4429
2.2	0.4820	0.4572	0.4440	0.4429	0.4429	0.4429
2.3	0.4798	0.4562	0.4429	0.4429	0.4429	0.4429
2.4	0.4777	0.4552	0.4429	0.4429	0.4429	0.4429
2.5	0.4755	0.4542	0.4429	0.4429	0.4429	0.4429
2.6	0.4734	0.4532	0.4429	0.4429	0.4429	0.4429
2.7	0.4712	0.4521	0.4429	0.4429	0.4429	0.4429
2.8	0.4699	0.4511	0.4429	0.4429	0.4429	0.4429
2.9	0.4694	0.4501	0.4429	0.4429	0.4429	0.4429
3.0	0.4688	0.4491	0.4429	0.4429	0.4429	0.4429

TABLE II (9) : EFFECTIVE SHADING COEFFICIENTS OF VERTICAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS

ORIENTATION : NORTH & SOUTH						
R_2	0º	10º	20º	30º	40º	50º
0.1	0.9526	0.9534	0.9549	0.9571	0.9606	0.9638
0.2	0.9066	0.9082	0.9110	0.9155	0.9225	0.9289
0.3	0.8605	0.8630	0.8672	0.8739	0.8844	0.8940
0.4	0.8144	0.8177	0.8236	0.8325	0.8463	0.8591
0.5	0.7752	0.7800	0.7892	0.8005	0.8159	0.8277
0.6	0.7540	0.7563	0.7632	0.7768	0.7950	0.8078
0.7	0.7379	0.7434	0.7464	0.7560	0.7771	0.7920
0.8	0.7290	0.7306	0.7348	0.7423	0.7637	0.7807
0.9	0.7202	0.7230	0.7269	0.7319	0.7507	0.7699
1.0	0.7114	0.7183	0.7190	0.7246	0.7388	0.7595
1.1	0.7060	0.7137	0.7144	0.7173	0.7308	0.7523
1.2	0.7022	0.7091	0.7098	0.7099	0.7251	0.7451
1.3	0.7000	0.7045	0.7053	0.7055	0.7206	0.7379
1.4	0.6977	0.6999	0.7007	0.7022	0.7173	0.7307
1.5	0.6954	0.6961	0.6981	0.7003	0.7141	0.7236
1.6	0.6932	0.6939	0.6960	0.6983	0.7109	0.7173
1.7	0.6909	0.6916	0.6940	0.6964	0.7077	0.7131
1.8	0.6886	0.6894	0.6919	0.6945	0.7044	0.7105
1.9	0.6864	0.6889	0.6899	0.6926	0.7012	0.7078
2.0	0.6841	0.6886	0.6878	0.6907	0.6980	0.7052
2.1	0.6818	0.6884	0.6858	0.6888	0.6948	0.7026
2.2	0.6796	0.6881	0.6853	0.6869	0.6915	0.7000
2.3	0.6773	0.6879	0.6849	0.6849	0.6910	0.6979
2.4	0.6750	0.6876	0.6845	0.6830	0.6909	0.6967
2.5	0.6728	0.6873	0.6841	0.6811	0.6908	0.6954
2.6	0.6705	0.6871	0.6837	0.6792	0.6908	0.6942
2.7	0.6695	0.6868	0.6833	0.6773	0.6907	0.6930
2.8	0.6686	0.6866	0.6829	0.6754	0.6906	0.6917
2.9	0.6677	0.6863	0.6826	0.6735	0.6905	0.6905
3.0	0.6668	0.6860	0.6822	0.6716	0.6904	0.6893

TABLE II (10) : EFFECTIVE SHADING COEFFICIENTS OF VERTICAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS

ORIENTATION : EAST & WEST						
R_2	0º	10º	20º	30º	40º	50º
0.1	0.9805	0.9751	0.9704	0.9653	0.9584	0.9520
0.2	0.9607	0.9499	0.9406	0.9302	0.9166	0.9038
0.3	0.9409	0.9247	0.9108	0.8952	0.8747	0.8555
0.4	0.9223	0.9007	0.8821	0.8614	0.8338	0.8078
0.5	0.9047	0.8774	0.8537	0.8275	0.7931	0.7606
0.6	0.8870	0.8543	0.8259	0.7939	0.7523	0.7133
0.7	0.8694	0.8313	0.7980	0.7616	0.7129	0.6671
0.8	0.8518	0.8090	0.7728	0.7312	0.6753	0.6227
0.9	0.8348	0.7884	0.7476	0.7014	0.6406	0.5823
1.0	0.8193	0.7678	0.7233	0.6747	0.6098	0.5493
1.1	0.8057	0.7471	0.7015	0.6511	0.5850	0.5184
1.2	0.7921	0.7287	0.6810	0.6320	0.5605	0.4880
1.3	0.7785	0.7120	0.6631	0.6135	0.5361	0.4633
1.4	0.7654	0.6960	0.6482	0.5949	0.5120	0.4577
1.5	0.7541	0.6826	0.6334	0.5764	0.4899	0.4526
1.6	0.7441	0.6696	0.6187	0.5579	0.4820	0.4474
1.7	0.7349	0.6589	0.6042	0.5397	0.4790	0.4422
1.8	0.7257	0.6485	0.5906	0.5220	0.4760	0.4371
1.9	0.7185	0.6381	0.5770	0.5065	0.4730	0.4319
2.0	0.7122	0.6276	0.5634	0.4982	0.4700	0.4268
2.1	0.7070	0.6172	0.5497	0.4966	0.4670	0.4221
2.2	0.7036	0.6076	0.5362	0.4950	0.4641	0.4185
2.3	0.7019	0.5987	0.5232	0.4934	0.4611	0.4158
2.4	0.7007	0.5897	0.5101	0.4918	0.4581	0.4145
2.5	0.6999	0.5808	0.4971	0.4902	0.4551	0.4132
2.6	0.6990	0.5718	0.4849	0.4886	0.4521	0.4119
2.7	0.6982	0.5629	0.4747	0.4870	0.4491	0.4105
2.8	0.6974	0.5539	0.4668	0.4859	0.4461	0.4092
2.9	0.6965	0.5450	0.4616	0.4850	0.4431	0.4082
3.0	0.6957	0.5360	0.4591	0.4841	0.4401	0.4080

TABLE II (11) : EFFECTIVE SHADING COEFFICIENTS OF VERTICAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS

ORIENTATION : NORTH-EAST & NORTH-WEST						
R_2	0º	10º	20º	30º	40º	50º
0.1	0.9517	0.9445	0.9389	0.9346	0.9317	0.9314
0.2	0.9074	0.8931	0.8819	0.8729	0.8670	0.8650
0.3	0.8646	0.8436	0.8268	0.8131	0.8036	0.8005
0.4	0.8262	0.7991	0.7770	0.7585	0.7449	0.7381
0.5	0.7912	0.7573	0.7297	0.7066	0.6895	0.6809
0.6	0.7562	0.7155	0.6824	0.6546	0.6342	0.6239
0.7	0.7230	0.6740	0.6356	0.6043	0.5832	0.5701
0.8	0.6899	0.6352	0.6038	0.5836	0.5643	0.5493
0.9	0.6575	0.6158	0.5921	0.5683	0.5465	0.5296
1.0	0.6359	0.6069	0.5806	0.5530	0.5288	0.5104
1.1	0.6300	0.5981	0.5691	0.5380	0.5125	0.5005
1.2	0.6240	0.5892	0.5576	0.5241	0.5038	0.4958
1.3	0.6181	0.5803	0.5461	0.5146	0.4984	0.4915
1.4	0.6121	0.5715	0.5348	0.5091	0.4946	0.4898
1.5	0.6061	0.5626	0.5257	0.5050	0.4908	0.4884
1.6	0.6002	0.5537	0.5201	0.5028	0.4881	0.4869
1.7	0.5942	0.5449	0.5161	0.5006	0.4874	0.4854
1.8	0.5883	0.5365	0.5120	0.4985	0.4867	0.4840
1.9	0.5823	0.5291	0.5094	0.4963	0.4860	0.4825
2.0	0.5763	0.5235	0.5079	0.4941	0.4853	0.4811
2.1	0.5704	0.5198	0.5064	0.4939	0.4846	0.4798
2.2	0.5644	0.5166	0.5050	0.4936	0.4839	0.4795
2.3	0.5590	0.5135	0.5035	0.4933	0.4831	0.4791
2.4	0.5541	0.5104	0.5020	0.4931	0.4824	0.4788
2.5	0.5494	0.5073	0.5005	0.4928	0.4817	0.4785
2.6	0.5452	0.5042	0.4991	0.4925	0.4810	0.4781
2.7	0.5410	0.5027	0.4976	0.4923	0.4803	0.4778
2.8	0.5376	0.5014	0.4961	0.4920	0.4796	0.4775
2.9	0.5349	0.5002	0.4946	0.4917	0.4788	0.4772
3.0	0.5323	0.4989	0.4941	0.4914	0.4781	0.4768

TABLE II (12) : EFFECTIVE SHADING COEFFICIENTS OF VERTICAL PROJECTION AT VARIOUS ANGLES OF INCLINATIONS

ORIENTATION : SOUTH-EAST & SOUTH-WEST						
R_2	0º	10º	20º	30º	40º	50º
0.1	0.9528	0.9457	0.9396	0.9351	0.9317	0.9304
0.2	0.9081	0.8938	0.8815	0.8724	0.8654	0.8624
0.3	0.8650	0.8437	0.8253	0.8113	0.8005	0.7955
0.4	0.8257	0.7988	0.7746	0.7555	0.7395	0.7307
0.5	0.7907	0.7570	0.7269	0.7029	0.6829	0.6715
0.6	0.7561	0.7153	0.6791	0.6504	0.6264	0.6127
0.7	0.7229	0.6743	0.6313	0.5978	0.5698	0.5539
0.8	0.6897	0.6342	0.5861	0.5629	0.5412	0.5242
0.9	0.6565	0.5987	0.5700	0.5474	0.5235	0.5045
1.0	0.6233	0.5863	0.5584	0.5324	0.5059	0.4850
1.1	0.6056	0.5771	0.5470	0.5185	0.4984	0.4737
1.2	0.5983	0.5685	0.5357	0.5046	0.4792	0.4670
1.3	0.5915	0.5599	0.5244	0.4946	0.4717	0.4627
1.4	0.5853	0.5513	0.5130	0.4882	0.4677	0.4586
1.5	0.5791	0.5427	0.5037	0.4831	0.4642	0.4572
1.6	0.5730	0.5341	0.4966	0.4790	0.4612	0.4557
1.7	0.5668	0.5255	0.4915	0.4771	0.4583	0.4543
1.8	0.5606	0.5169	0.4876	0.4752	0.4577	0.4528
1.9	0.5547	0.5096	0.4836	0.4734	0.4571	0.4514
2.0	0.5499	0.5043	0.4796	0.4715	0.4565	0.4499
2.1	0.5451	0.4990	0.4772	0.4696	0.4558	0.4485
2.2	0.5403	0.4938	0.4757	0.4677	0.4552	0.4471
2.3	0.5355	0.4909	0.4741	0.4662	0.4546	0.4456
2.4	0.5307	0.4879	0.4726	0.4661	0.4540	0.4446
2.5	0.5258	0.4850	0.4711	0.4660	0.4534	0.4443
2.6	0.5210	0.4820	0.4695	0.4659	0.4528	0.4439
2.7	0.5168	0.4790	0.4680	0.4658	0.4522	0.4435
2.8	0.5135	0.4761	0.4665	0.4657	0.4516	0.4432
2.9	0.5110	0.4735	0.4649	0.4656	0.4510	0.4429
3.0	0.5084	0.4715	0.4634	0.4655	0.4504	0.4429

TABLE II (13A) : EFFECTIVE SHADING COEFFICIENTS OF EGG-CRATE LOUVRES WITH INCLINED HORIZONTAL FINS

ORIENTATION : NORTH &SOUTH						
R_1	R_2	0º	10º	20º	30º	40º
0.2	0.2	0.8125	0.8053	0.8011	0.8002	0.8025
0.2	0.4	0.7476	0.7432	0.7409	0.7409	0.7431
0.2	0.6	0.7086	0.7059	0.7047	0.7050	0.7068
0.2	0.8	0.6945	0.6926	0.6917	0.6920	0.6934
0.2	1.0	0.6850	0.6836	0.6829	0.6832	0.6843
0.2	1.2	0.6802	0.6790	0.6785	0.6787	0.6796
0.2	1.4	0.6779	0.6768	0.6764	0.6766	0.6774
0.2	1.6	0.6756	0.6747	0.6743	0.6744	0.6752
0.2	1.8	0.6733	0.6725	0.6722	0.6723	0.6729
0.4	0.2	0.7184	0.7070	0.7002	0.6977	0.6995
0.4	0.4	0.6808	0.6747	0.6716	0.6709	0.6727
0.4	0.6	0.6631	0.6604	0.6593	0.6594	0.6605
0.4	0.8	0.6601	0.6586	0.6581	0.6581	0.6587
0.4	1.0	0.6587	0.6580	0.6578	0.6578	0.6580
0.4	1.2	0.6582	0.6577	0.6577	0.6577	0.6577
0.4	1.4	0.6581	0.6577	0.6577	0.6577	0.6577
0.4	1.6	0.6581	0.6577	0.6577	0.6577	0.6577
0.4	1.8	0.6581	0.6577	0.6577	0.6577	0.6577
0.6	0.2	0.6840	0.6769	0.6728	0.6703	0.6687
0.6	0.4	0.6638	0.6618	0.6608	0.6602	0.6599
0.6	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.8	0.6577	0.6577	0.6577	0.6577	0.6577

TABLE II (13B)

ORIENTATION : NORTH &SOUTH						
R_1	R_2	0º	10º	20º	30º	40º
0.8	0.2	0.6740	0.6688	0.6645	0.6622	0.6612
0.8	0.4	0.6609	0.6598	0.6589	0.6584	0.6583
0.8	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	0.2	0.6681	0.6638	0.6619	0.6603	0.6590
1.0	0.4	0.6595	0.6586	0.6584	0.6581	0.6579
1.0	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	0.2	0.6651	0.6626	0.6603	0.6584	0.6577
1.2	0.4	0.6588	0.6585	0.6581	0.6578	0.6577
1.2	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.8	0.6577	0.6577	0.6577	0.6577	0.6577

TABLE II (13C)

ORIENTATION : NORTH &SOUTH						
R_1	R_2	0º	10º	20º	30º	40º
1.4	0.2	0.6642	0.6613	0.6587	0.6577	0.6577
1.4	0.4	0.6587	0.6583	0.6579	0.6577	0.6577
1.4	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	0.2	0.6634	0.6601	0.6580	0.6577	0.6577
1.6	0.4	0.6586	0.6581	0.6578	0.6577	0.6577
1.6	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	0.2	0.6626	0.6589	0.6577	0.6577	0.6577
1.8	0.4	0.6584	0.6579	0.6577	0.6577	0.6577
1.8	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.8	0.6577	0.6577	0.6577	0.6577	0.6577

TABLE II (14A) : EFFECTIVE SHADING COEFFICIENTS OF EGG-CRATE LOUVRES WITH INCLINED HORIZONTAL FINS

ORIENTATION : EAST & WEST						
R_1	R_2	0º	10º	20º	30º	40º
0.2	0.2	0.8482	0.8306	0.8165	0.8064	0.8013
0.2	0.4	0.8212	0.8047	0.7914	0.7818	0.7769
0.2	0.6	0.7942	0.7788	0.7663	0.7572	0.7525
0.2	0.8	0.7672	0.7529	0.7412	0.7327	0.7282
0.2	1.0	0.7417	0.7284	0.7175	0.7095	0.7052
0.2	1.2	0.7190	0.7066	0.6965	0.6890	0.6850
0.2	1.4	0.6968	0.6852	0.6758	0.6688	0.6652
0.2	1.6	0.6786	0.6677	0.6589	0.6524	0.6490
0.2	1.8	0.6626	0.6523	0.6440	0.6379	0.6348
0.4	0.2	0.7513	0.7162	0.6883	0.6678	0.6556
0.4	0.4	0.7323	0.6993	0.6730	0.6535	0.6418
0.4	0.6	0.7133	0.6825	0.6577	0.6393	0.6280
0.4	0.8	0.6943	0.6656	0.6424	0.6251	0.6143
0.4	1.0	0.6754	0.6488	0.6271	0.6108	0.6006
0.4	1.2	0.6570	0.6322	0.6118	0.5967	0.5871
0.4	1.4	0.6389	0.6158	0.5968	0.5827	0.5738
0.4	1.6	0.6235	0.6017	0.5840	0.5708	0.5625
0.4	1.8	0.6096	0.5890	0.5723	0.5599	0.5523
0.6	0.2	0.6768	0.6307	0.5917	0.5611	0.5398
0.6	0.4	0.6626	0.6190	0.5822	0.5532	0.5329
0.6	0.6	0.6483	0.6073	0.5726	0.5452	0.5260
0.6	0.8	0.6341	0.5956	0.5630	0.5372	0.5191
0.6	1.0	0.6198	0.5840	0.5535	0.5293	0.5121
0.6	1.2	0.6056	0.5723	0.5439	0.5213	0.5052
0.6	1.4	0.5915	0.5607	0.5344	0.5134	0.4984
0.6	1.6	0.5788	0.5500	0.5254	0.5058	0.4917
0.6	1.8	0.5668	0.5398	0.5167	0.4983	0.4852

TABLE II (14B)

ORIENTATION : EAST & WEST						
R_1	R_2	0º	10º	20º	30º	40º
0.8	0.2	0.6135	0.5615	0.5215	0.4881	0.4622
0.8	0.4	0.6033	0.5537	0.5157	0.4839	0.4593
0.8	0.6	0.5931	0.5459	0.5099	0.4798	0.4564
0.8	0.8	0.5829	0.5381	0.5041	0.4756	0.4534
0.8	1.0	0.5727	0.5304	0.4983	0.4714	0.4505
0.8	1.2	0.5625	0.5226	0.4925	0.4673	0.4476
0.8	1.4	0.5523	0.5148	0.4867	0.4631	0.4447
0.8	1.6	0.5421	0.5070	0.4809	0.4589	0.4418
0.8	1.8	0.5320	0.4992	0.4751	0.4548	0.4389
1.0	0.2	0.5744	0.5178	0.4695	0.4422	0.4212
1.0	0.4	0.5661	0.5123	0.4663	0.4401	0.4201
1.0	0.6	0.5578	0.5068	0.4631	0.4381	0.4191
1.0	0.8	0.5495	0.5014	0.4599	0.4361	0.4180
1.0	1.0	0.5412	0.4959	0.4567	0.4341	0.4170
1.0	1.2	0.5329	0.4904	0.4535	0.4321	0.4159
1.0	1.4	0.5246	0.4849	0.4503	0.4301	0.4149
1.0	1.6	0.5163	0.4795	0.4471	0.4280	0.4138
1.0	1.8	0.5080	0.4740	0.4439	0.4260	0.4128
1.2	0.2	0.5420	0.4791	0.4447	0.4144	0.4033
1.2	0.4	0.5354	0.4754	0.4426	0.4137	0.4030
1.2	0.6	0.5289	0.4717	0.4405	0.4130	0.4027
1.2	0.8	0.5223	0.4680	0.4384	0.4123	0.4024
1.2	1.0	0.5158	0.4643	0.4363	0.4117	0.4021
1.2	1.2	0.5092	0.4606	0.4342	0.4110	0.4018
1.2	1.4	0.5027	0.4569	0.4321	0.4103	0.4015
1.2	1.6	0.4961	0.4532	0.4300	0.4096	0.4012
1.2	1.8	0.4896	0.4495	0.4279	0.4089	0.4009

TABLE II (14C)

ORIENTATION : EAST & WEST						
R_1	R_2	0º	10º	20º	30º	40º
1.4	0.2	0.5107	0.4621	0.4220	0.4055	0.3969
1.4	0.4	0.5058	0.4592	0.4210	0.4051	0.3969
1.4	0.6	0.5008	0.4563	0.4200	0.4047	0.3969
1.4	0.8	0.4959	0.4535	0.4190	0.4043	0.3969
1.4	1.0	0.4910	0.4506	0.4180	0.4039	0.3969
1.4	1.2	0.4860	0.4477	0.4170	0.4035	0.3969
1.4	1.4	0.4811	0.4449	0.4160	0.4031	0.3969
1.4	1.6	0.4762	0.4420	0.4150	0.4028	0.3969
1.4	1.8	0.4712	0.4391	0.4140	0.4024	0.3969
1.6	0.2	0.4951	0.4451	0.4117	0.3998	0.3963
1.6	0.4	0.4907	0.4431	0.4110	0.3997	0.3963
1.6	0.6	0.4863	0.4410	0.4103	0.3996	0.3963
1.6	0.8	0.4820	0.4390	0.4096	0.3995	0.3963
1.6	1.0	0.4776	0.4369	0.4089	0.3994	0.3963
1.6	1.2	0.4732	0.4349	0.4083	0.3993	0.3963
1.6	1.4	0.4688	0.4329	0.4076	0.3992	0.3963
1.6	1.6	0.4644	0.4308	0.4069	0.3991	0.3963
1.6	1.8	0.4600	0.4288	0.4062	0.3990	0.3963
1.8	0.2	0.4844	0.4281	0.4075	0.3963	0.3963
1.8	0.4	0.4805	0.4269	0.4070	0.3963	0.3963
1.8	0.6	0.4767	0.4257	0.4065	0.3963	0.3963
1.8	0.8	0.4728	0.4245	0.4061	0.3963	0.3963
1.8	1.0	0.4690	0.4233	0.4056	0.3963	0.3963
1.8	1.2	0.4651	0.4221	0.4051	0.3963	0.3963
1.8	1.4	0.4613	0.4208	0.4047	0.3963	0.3963
1.8	1.6	0.4574	0.4196	0.4042	0.3963	0.3963
1.8	1.8	0.4536	0.4184	0.4037	0.3963	0.3963

TABLE II (15A) : EFFECTIVE SHADING COEFFICIENTS OF EGG-CRATE LOUVRES WITH INCLINED HORIZONTAL FINS

ORIENTATION : NORTH-EAST & NORTH-WEST						
R_1	R_2	0º	10º	20º	30º	40º
0.2	0.2	0.8019	0.7886	0.7788	0.7727	0.7705
0.2	0.4	0.7439	0.7331	0.7250	0.7198	0.7178
0.2	0.6	0.6944	0.6857	0.6790	0.6746	0.6727
0.2	0.8	0.6452	0.6384	0.6332	0.6298	0.6281
0.2	1.0	0.6024	0.5973	0.5935	0.5909	0.5897
0.2	1.2	0.5926	0.5880	0.5844	0.5820	0.5809
0.2	1.4	0.5829	0.5786	0.5754	0.5732	0.5722
0.2	1.6	0.5732	0.5693	0.5663	0.5644	0.5635
0.2	1.8	0.5634	0.5599	0.5573	0.5555	0.5548
0.4	0.2	0.7138	0.6898	0.6709	0.6573	0.6494
0.4	0.4	0.6724	0.6527	0.6371	0.6258	0.6192
0.4	0.6	0.6369	0.6207	0.6079	0.5986	0.5933
0.4	0.8	0.6013	0.5887	0.5787	0.5715	0.5673
0.4	1.0	0.5688	0.5593	0.5519	0.5466	0.5436
0.4	1.2	0.5613	0.5524	0.5455	0.5407	0.5380
0.4	1.4	0.5537	0.5456	0.5392	0.5348	0.5325
0.4	1.6	0.5462	0.5387	0.5329	0.5290	0.5270
0.4	1.8	0.5386	0.5318	0.5266	0.5231	0.5214
0.6	0.2	0.6479	0.6186	0.5951	0.5766	0.5636
0.6	0.4	0.6178	0.5934	0.5741	0.5588	0.5481
0.6	0.6	0.5920	0.5718	0.5560	0.5435	0.5348
0.6	0.8	0.5663	0.5502	0.5379	0.5282	0.5214
0.6	1.0	0.5416	0.5294	0.5204	0.5134	0.5085
0.6	1.2	0.5353	0.5240	0.5159	0.5095	0.5051
0.6	1.4	0.5289	0.5186	0.5113	0.5056	0.5018
0.6	1.6	0.5225	0.5132	0.5067	0.5017	0.4984
0.6	1.8	0.5161	0.5078	0.5022	0.4978	0.4950

TABLE II (15B)

ORIENTATION : NORTH-EAST & NORTH-WEST						
R_1	R_2	0º	10º	20º	30º	40º
0.8	0.2	0.6089	0.5719	0.5445	0.5270	0.5133
0.8	0.4	0.5855	0.5551	0.5328	0.5182	0.5067
0.8	0.6	0.5652	0.5403	0.5225	0.5104	0.5010
0.8	0.8	0.5449	0.5255	0.5122	0.5027	0.4952
0.8	1.0	0.5252	0.5109	0.5019	0.4949	0.4895
0.8	1.2	0.5199	0.5070	0.4989	0.4927	0.4879
0.8	1.4	0.5147	0.5030	0. 4960	0.4905	0.4863
0.8	1.6	0.5095	0.4991	0. 4930	0.4883	0.4847
0.8	1.8	0.5042	0.4952	0. 4900	0.4861	0.4831
1.0	0.2	0.5750	0.5440	0. 5183	0.5005	0.4878
1.0	0.4	0.5579	0.5321	0. 5105	0.4960	0.4856
1.0	0.6	0. 5429	0.5218	0. 5039	0.4922	0.4839
1.0	0.8	0. 5279	0.5114	0. 4972	0.4884	0.4822
1.0	1.0	0.5129	0.5010	0.4905	0.4847	0.4805
1.0	1.2	0.5087	0.4981	0.4888	0.4836	0.4799
1.0	1.4	0.5045	0.4952	0.4870	0.4825	0.4793
1.0	1.6	0.5002	0.4922	0.4852	0.4814	0.4787
1.0	1.8	0.4960	0.4893	0.4834	0.4803	0.4781
1.2	0.2	0.5577	0.5232	0.5002	0.4857	0.4802
1.2	0.4	0.5434	0.5144	0.4958	0.4838	0.4795
1.2	0.6	0.5309	0.5069	0.4922	0.4822	0.4787
1.2	0.8	0.5185	0.4994	0.4886	0.4806	0.4780
1.2	1.0	0.5060	0.4919	0.4850	0.4789	0.4773
1.2	1.2	0.5025	0.4900	0.4839	0.4785	0.4771
1.2	1.4	0.4990	0.4880	0.4827	0.4781	0.4769
1.2	1.6	0.4955	0.4860	0.4816	0.4777	0.4767
1.2	1.8	0.4919	0.4840	0.4804	0.4773	0.4765

TABLE II (15C)

ORIENTATION : NORTH-EAST & NORTH-WEST						
R_1	R_2	0º	10º	20º	30º	40º
1.4	0.2	0.5424	0.5101	0.4894	0.4815	0.4759
1.4	0.4	0.5303	0.5039	0.4868	0.4805	0.4759
1.4	0.6	0.5199	0.4987	0.4846	0.4796	0.4759
1.4	0.8	0.5095	0.4936	0.4825	0.4786	0.4759
1.4	1.0	0.4991	0.4884	0.4803	0.4777	0.4759
1.4	1.2	0.4963	0.4868	0.4797	0.4774	0.4759
1.4	1.4	0.4935	0.4853	0.4791	0.4772	0.4759
1.4	1.6	0.4907	0.4837	0.4785	0.4770	0.4759
1.4	1.8	0.4879	0.4821	0.4779	0.4767	0.4759
1.6	0.2	0.5310	0.4994	0.4856	0.4777	0.4759
1.6	0.4	0.5208	0.4952	0.4838	0.4774	0.4759
1.6	0.6	0.5122	0.4917	0.4822	0.4771	0.4759
1.6	0.8	0.5036	0.4883	0.4806	0.4768	0.4759
1.6	1.0	0.4949	0.4848	0.4790	0.4765	0.4759
1.6	1.2	0.4926	0.4837	0.4785	0.4764	0.4759
1.6	1.4	0.4902	0.4825	0.4781	0.4763	0.4759
1.6	1.6	0.4879	0.4814	0.4777	0.4762	0.4759
1.6	1.8	0.4855	0.4803	0.4773	0.4761	0.4759
1.8	0.2	0.5221	0.4930	0.4826	0.4759	0.4759
1.8	0.4	0.5137	0.4897	0.4815	0.4759	0.4759
1.8	0.6	0.5067	0.4869	0.4803	0.4759	0.4759
1.8	0.8	0.4997	0.4841	0.4792	0.4759	0.4759
1.8	1.0	0.4926	0.4813	0.4780	0.4759	0.4759
1.8	1.2	0.4906	0.4806	0.4777	0.4759	0.4759
1.8	1.4	0.4885	0.4798	0.4775	0.4759	0.4759
1.8	1.6	0.4864	0.4791	0.4772	0.4759	0.4759
1.8	1.8	0.4843	0.4784	0.4769	0.4759	0.4759

TABLE II (16A) : EFFECTIVE SHADING COEFFICIENTS OF EGG-CRATE LOUVRES WITH INCLINED HORIZONTAL FINS

ORIENTATION : SOUTH-EAST & SOUTH-WEST						
R_1	R_2	0º	10º	20º	30º	40º
0.2	0.2	0.7951	0.7808	0.7702	0.7634	0.7608
0.2	0.4	0.7351	0.7233	0.7144	0.7087	0.7064
0.2	0.6	0.6842	0.6745	0.6672	0.6623	0.6602
0.2	0.8	0.6340	0.6264	0.6205	0.6167	0.6149
0.2	1.0	0.5838	0.5782	0.5739	0.5710	0.5696
0.2	1.2	0.5669	0.5620	0.5581	0.5555	0.5542
0.2	1.4	0.5570	0.5525	0.5489	0.5465	0.5453
0.2	1.6	0.5471	0.5430	0.5397	0.5375	0.5364
0.2	1.8	0.5372	0.5334	0.5305	0.5285	0.5275
0.4	0.2	0.6979	0.6713	0.6510	0.6365	0.6285
0.4	0.4	0.6555	0.6334	0.6165	0.6044	0.5977
0.4	0.6	0.6193	0.6008	0.5868	0.5768	0.5713
0.4	0.8	0.5831	0.5683	0.5572	0.5492	0.5449
0.4	1.0	0.5469	0.5358	0.5275	0.5216	0.5185
0.4	1.2	0.5361	0.5263	0.5188	0.5135	0.5107
0.4	1.4	0.5286	0.5196	0.5127	0.5078	0.5053
0.4	1.6	0.5212	0.5129	0.5066	0.5022	0.4999
0.4	1.8	0.5137	0.5063	0.5005	0.4965	0.4944
0.6	0.2	0.6266	0.5923	0.5677	0.5483	0.5347
0.6	0.4	0.5959	0.5670	0.5466	0.5305	0.5192
0.6	0.6	0.5694	0.5452	0.5283	0.5150	0.5057
0.6	0.8	0.5430	0.5235	0.5101	0.4996	0.4923
0.6	1.0	0.5166	0.5018	0.4919	0.4842	0.4788
0.6	1.2	0.5091	0.4957	0.4868	0.4798	0.4751
0.6	1.4	0.5030	0.4905	0.4824	0.4761	0.4718
0.6	1.6	0.4969	0.4853	0.4780	0.4723	0.4685
0.6	1.8	0.4907	0.4801	0.4736	0.4685	0.4652

TABLE II (16B)

ORIENTATION : SOUTH-EAST & SOUTH-WEST						
R_1	R_2	0º	10º	20º	30º	40º
0.8	0.2	0.5821	0.5434	0.5133	0.4954	0.4814
0.8	0.4	0.5586	0.5264	0.5016	0.4865	0.4747
0.8	0.6	0.5381	0.5114	0.4912	0.4787	0.4689
0.8	0.8	0.5176	0.4964	0.4808	0.4709	0.4631
0.8	1.0	0.4971	0.4815	0.4705	0.4630	0.4573
0.8	1.2	0.4914	0.4773	0.4675	0.4609	0.4557
0.8	1.4	0.4863	0.4734	0.4646	0.4587	0.4541
0.8	1.6	0.4812	0.4695	0.4616	0.4565	0.4525
0.8	1.8	0.4761	0.4656	0.4587	0.4543	0.4509
1.0	0.2	0.5448	0.5129	0.4864	0.4682	0.4552
1.0	0.4	0.5277	0.5009	0.4786	0.4637	0.4531
1.0	0.6	0.5125	0.4904	0.4719	0.4599	0.4514
1.0	0.8	0.4973	0.4800	0.4652	0.4561	0.4497
1.0	1.0	0.4822	0.4695	0.4585	0.4523	0.4480
1.0	1.2	0.4779	0.4666	0.4566	0.4512	0.4474
1.0	1.4	0.4738	0.4637	0.4548	0.4501	0.4468
1.0	1.6	0.4696	0.4608	0.4530	0.4490	0.4461
1.0	1.8	0.4654	0.4579	0.4512	0.4478	0.4455
1.2	0.2	0.5269	0.4915	0.4679	0.4532	0.4471
1.2	0.4	0.5125	0.4827	0.4636	0.4513	0.4464
1.2	0.6	0.5000	0.4751	0.4600	0.4497	0.4457
1.2	0.8	0.4874	0.4675	0.4564	0.4481	0.4450
1.2	1.0	0.4748	0.4600	0.4528	0.4465	0.4443
1.2	1.2	0.4713	0.4579	0.4516	0.4461	0.4441
1.2	1.4	0.4678	0.4559	0.4504	0.4456	0.4439
1.2	1.6	0.4643	0.4539	0.4493	0.4452	0.4438
1.2	1.8	0.4608	0.4519	0.4481	0.4447	0.4436

TABLE II (16C)

ORIENTATION : SOUTH-EAST & SOUTH-WEST						
R_1	R_2	0º	10º	20º	30º	40º
1.4	0.2	0.5112	0.4781	0.4571	0.4483	0.4429
1.4	0.4	0.4991	0.4719	0.4545	0.4474	0.4429
1.4	0.6	0.4886	0.4668	0.4524	0.4465	0.4429
1.4	0.8	0.4781	0.4616	0.4502	0.4456	0.4429
1.4	1.0	0.4676	0.4564	0.4481	0.4447	0.4429
1.4	1.2	0.4647	0.4548	0.4474	0.4445	0.4429
1.4	1.4	0.4619	0.4532	0.4468	0.4442	0.4429
1.4	1.6	0.4590	0.4516	0.4462	0.4440	0.4429
1.4	1.8	0.4562	0.4500	0.4455	0.4438	0.4429
1.6	0.2	0.4995	0.4672	0.4522	0.4446	0.4429
1.6	0.4	0.4893	0.4631	0.4506	0.4443	0.4429
1.6	0.6	0.4806	0.4597	0.4491	0.4440	0.4429
1.6	0.8	0.4719	0.4563	0.4475	0.4437	0.4429
1.6	1.0	0.4633	0.4529	0.4460	0.4435	0.4429
1.6	1.2	0.4608	0.4517	0.4456	0.4434	0.4429
1.6	1.4	0.4584	0.4505	0.4452	0.4433	0.4429
1.6	1.6	0.4560	0.4493	0.4448	0.4432	0.4429
1.6	1.8	0.4536	0.4481	0.4444	0.4432	0.4429
1.8	0.2	0.4904	0.4609	0.4494	0.4429	0.4429
1.8	0.4	0.4821	0.4576	0.4483	0.4429	0.4429
1.8	0.6	0.4750	0.4549	0.4472	0.4429	0.4429
1.8	0.8	0.4680	0.4521	0.4461	0.4429	0.4429
1.8	1.0	0.4610	0.4493	0.4451	0.4429	0.4429
1.8	1.2	0.4588	0.4485	0.4448	0.4429	0.4429
1.8	1.4	0.4567	0.4477	0.4445	0.4429	0.4429
1.8	1.6	0.4545	0.4470	0.4442	0.4429	0.4429
1.8	1.8	0.4524	0.4462	0.4440	0.4429	0.4429

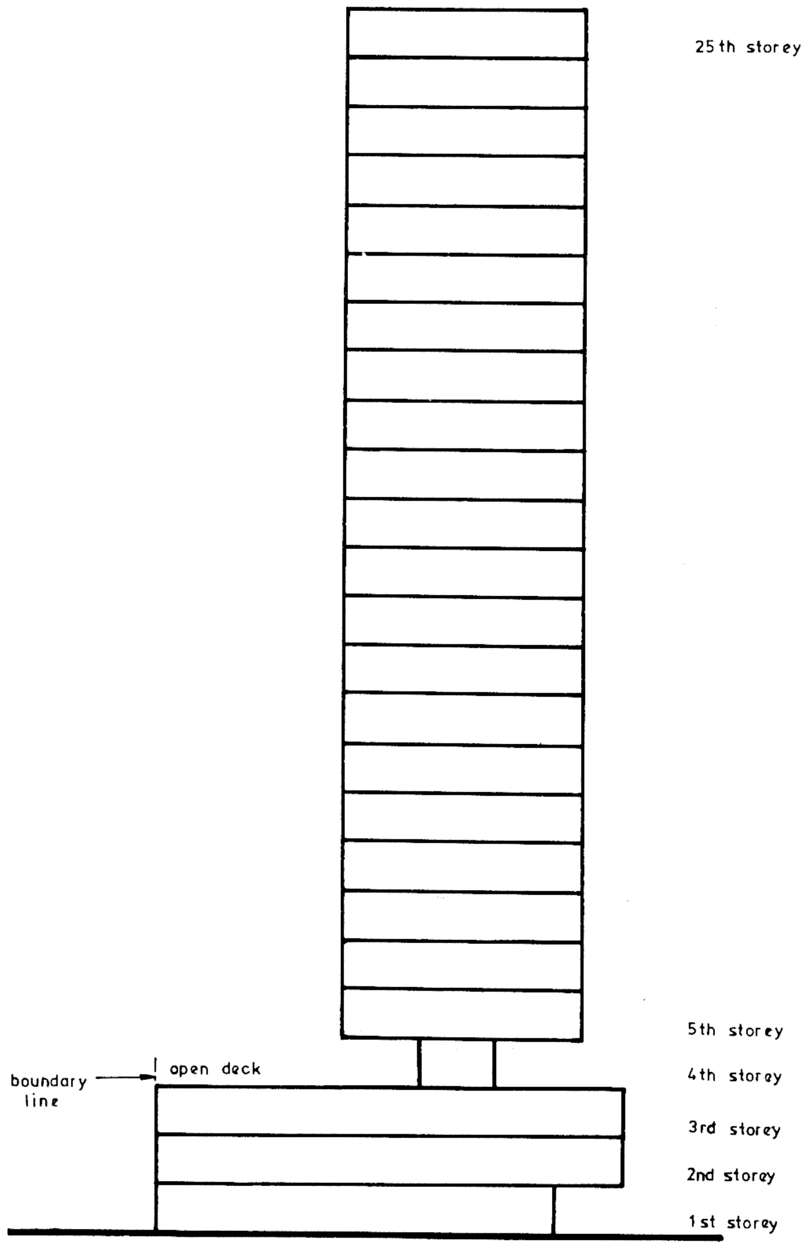
APPENDIX III EXAMPLE OF OTTV CALCULATION FOR A HYPOTHETICAL BUILDING

Brief Description of Building

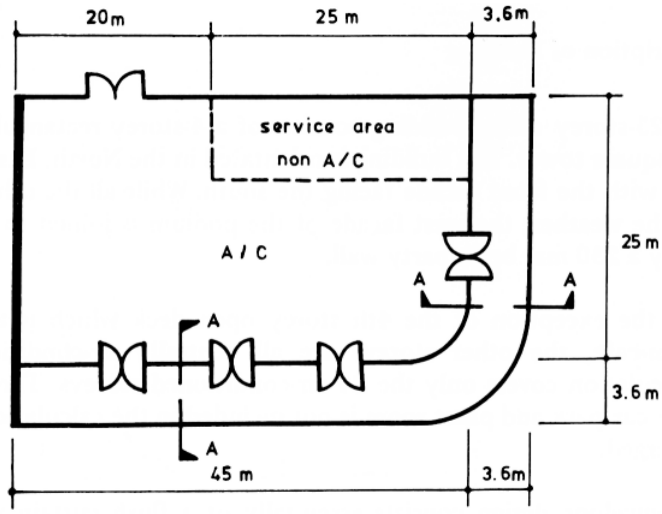
The 25-storey office building consists of a 4-storey rectangular podium and a 21-storey square tower. The building is orientated in the North, East, South and West directions with the front facade facing the south. While all the other facades are exposed to the weather, the west facade of the podium is joined to the neighbouring building by a 230 mm brick party wall.

With the exception of the 4th storey open deck which is a landscaped roof garden-cum-cafe, the other storeys are all centrally air-conditioned. Hence the OTTV calculation covers only the 24 air-conditioned storeys. The basement which houses the car park and plant room is not included in the calculation as it is completely submerged.

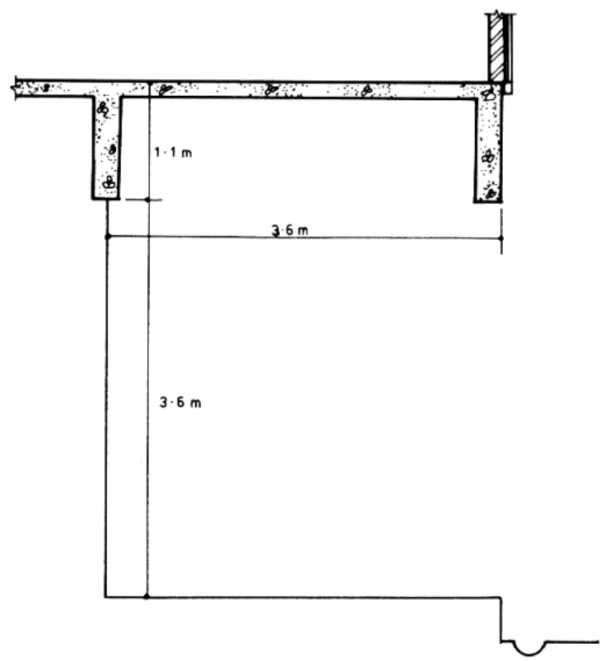
The envelope design consists essentially of a flush curtain wall construction with double glazing for the tower block as well as the east and south facades of the podium. The 1st storey facades on the east and south consist of an almost full height glass envelope shaded by a continuous overhang.



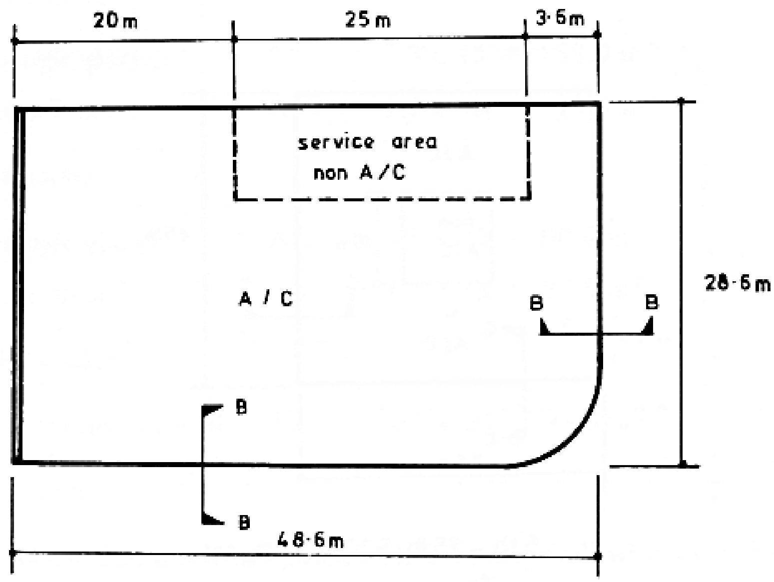
Sketch Drawing on Envelope Details



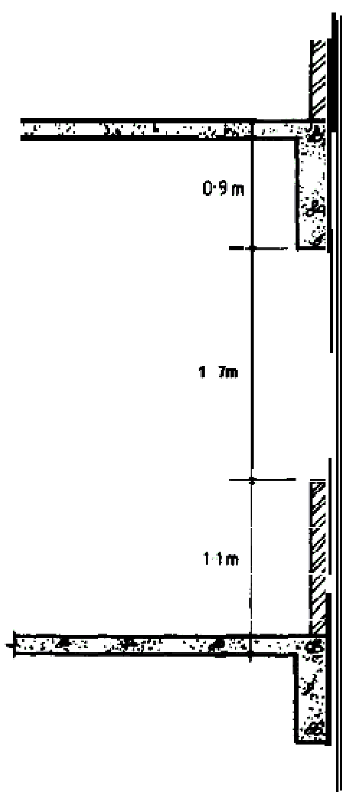
1st STOREY PLAN



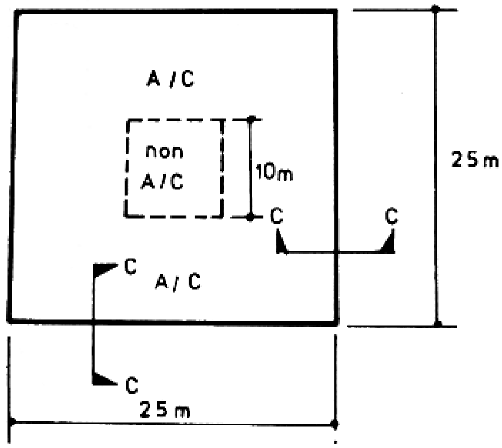
SECTION A -A



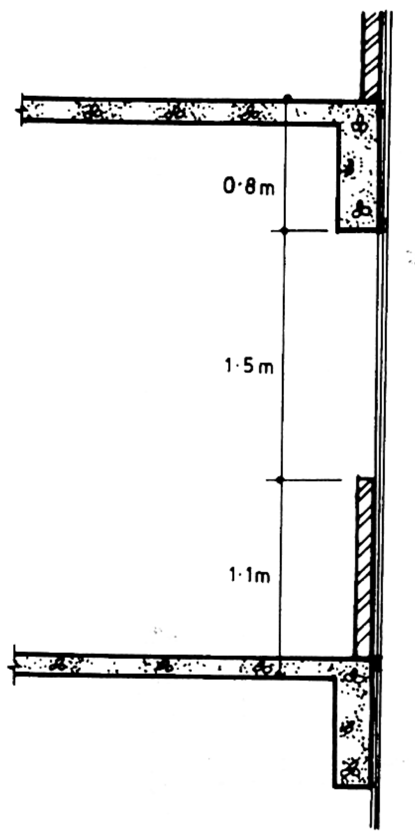
2nd & 3rd STOREY PLAN



SECTION B -B



5th - 25th STOREY PLAN



SECTION C- C

3 Envelope Area Calculation

3.1 Podium : 1st Storey

(i) South facade:

(a) single glazing $Af_1 = 3.6 \times 45$ $= 162.0\ m^2$

(b) r.c. beam $Aw_1 = 1.1 \times 45$ $= 49.5\ m^2$

(ii) East facade:

(a)	single glazing	$Af_1 = 3.6 \times 25$	$= 90.0\ m^2$
(b)	r.c. beam	$Aw_1 = 1.1 \times 25$	$= 27.5\ m^2$

(iii) North facade:

200 mm r.c. wall $Aw_2 = 4.7 \times 20$ $= 94.0\ m^2$

(iv) West facade:

As the 230 mm thick brick-wall is a party wall which is not exposed to the outside, it is not included in the calculation.

3.2 Podium : 2nd and 3rd Storeys (2 Storeys)

(i) South facade:

(a)	double glazing	$Af_2 = 1.7 \times 48.6 \times 2$	$= 165.2\ m^2$
(b)	r.c. beam with glass cladding	$Aw_3 = 0.9 \times 48.6 \times 2$	$= 87.5\ m^2$
(c)	brick parapet	$Aw_4 = 1.1 \times 48.6 \times 2$	$= 106.9\ m^2$

(ii) East facade:

(a)	double glazing	$Af_2 = 1.7 \times 28.6 \times 2$	$= 97.2\ m^2$
(b)	r.c. beam with glass cladding	$Aw_3 = 0.9 \times 28.6 \times 2$	$= 51.5\ m^2$
(c)	brick parapet	$Aw_4 = 1.1 \times 28.6 \times 2$	$= 62.9\ m^2$

(iii) North facade:

200 mm r.c. wall $Aw_2 = 3.7 \times (20 + 3.6) \times 2$ $= 174.6 m^2$

(iv) West facade:

Similar to 3.1 (iv).

3.3 Tower Block : 5th to 25th Storeys (21 Storeys)

(i) South facade:

(a)	double glazing	$Af_2 = 1.5 \times 25 \times 21$	$= 787.5\ m^2$
(b)	r.c. beam with glass cladding	$Aw_3 = 0.8 \times 25 \times 21$	$= 420.0\ m^2$
(c)	brick parapet	$Aw_4 = 1.1 \times 25 \times 21$	$= 577.5\ m^2$

(ii) East facade:

Similar to 3.3(i) above

(iii) North facade:

Similar to 3.3(i) above

(iv) West facade:

Similar to 3.3(i) above

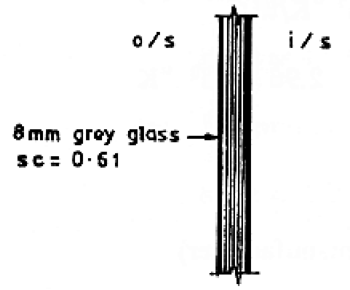
Summary of Envelope Area

Facade Orientation	Podium 1st Storey	Podium 2nd and 3rd Storeys	Tower 5th - 5th Storeys	Total	
South	single glazing Af_1 = 162.0	double glazing Af_2 = 165.2	double glazing Af_2 = 787.5	Af_1 = 162 .0	
				Af_2 = 952.7	
	r.c. beam Aw_1 = 49.5	r.c. beam with glass cladding Aw_3 = 87.5	r.c. beam with glass cladding Aw_3 = 420.0		Ao = 2356.1
		brick parapet with glass cladding Aw_4 = 106.9	brick parapet with glass cladding Aw_4 = 577.5	Aw_1 = 49.5	
				Aw_3 = 507.5	
				Aw_4 = 684.4	
East	single glazing Af_1 = 90.0	double glazing Af_2 = 97.2	double glazing Af_2 = 787.5	Af_1 = 90	
				Af_2 = 884.7	
	r.c. beam Aw_1 = 94.0	r.c. beam with glass cladding Aw_3 = 51.5	r.c. beam with glass cladding Aw_3 = 420.0		Ao = 2114.1
		brick parapet with glass cladding Aw_4 = 62.9	brick parapet with glass cladding Aw_4 = 577.5	Aw_1 = 27.5	
				Aw_3 = 471.5	
				Aw_4 = 640.4	
North	r.c. wall Aw_2 = 94.0	r.c. wall Aw_2 = 174.6	double glazing Af_2 = 787.5	Af_2 = 787.5	
			r.c. beam with glass cladding Aw_3 = 420.0	Aw_2 = 268.6	
			brick parapet with glasscladding Aw_4 = 577.5		Ao = 2053.6
				Aw_3 = 420.0	
				Aw_4 = 577.5	
West	-	-	double glazing Af_2 = 787.5	Af_2 = 787.5	
			r.c. beam with glass cladding Aw_3 = 420.0	Aw_3 = 420.0	
			brick parapet with glasscladding Aw_4 = 577.5		Ao = 1785
				Aw_4 = 577.5	

4 U-Value Calculation

4.1 Podium: 1st Storey

(a) 8mm single glazing (South & East facades)



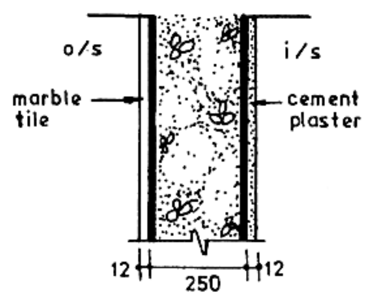
$$R = 0.044 + \frac{0.008}{1.053} + 0.12 = 0.172 m^2\,°K/W$$

$$U = \frac{1}{R} = 5.82 W/m^2 °K$$

$\Delta T = 5°K$

SCg = 0.61 (by manufacturer)

(b) 250mm r.c. beam (South & East facades)



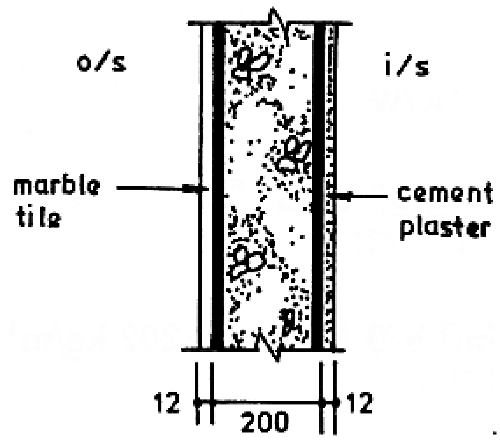
$$R = 0.044 + \frac{0.012}{1.298} + \frac{0.250}{1.442} + \frac{0.012}{0.533} + 0.12 = 0.369 m^2\,°K/W$$

$$U = \frac{1}{R} = 2.71 W/m^2\,°K$$

$$Weight \doteq 2400\,kg/m^3 \times 0.25m = 600\,kg/m^2$$

$\therefore\ TDeq = 10°K$

(c) 200mm r.c. wall (North facade)



$$R = 0.044 + \frac{0.012}{1.298} + \frac{0.200}{1.442} + \frac{0.012}{0.533} + 0.12 = 0.334 m^2\,°K/W$$

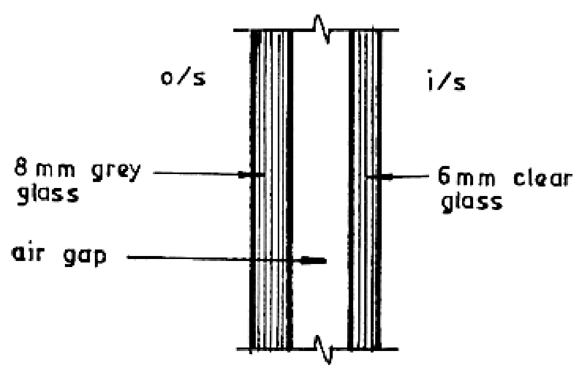
$$U = \frac{1}{R} = 2.99\,W/m^2\,°K$$

$$\text{Weight} \doteqdot 2400\,kg/m^3 \times 0.2m = 480\,kg/m^2$$

$$\therefore\ TDeq = 10°K$$

4.2 Podium: 2nd & 3rd Storeys

(a) double glazing (South & East facades)



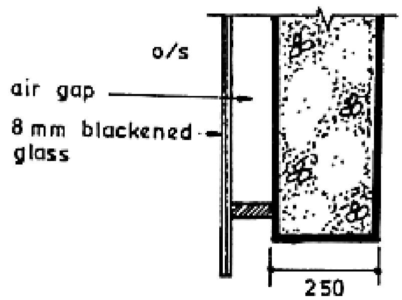
$$R = 0.044 + \frac{0.008}{1.053} + 0.16 + \frac{0.006}{1.053} + 0.12 = 0.337 m^2\,°K/W$$

$$U = \frac{1}{R} = 2.96 W/m^2\,°K$$

$$\Delta T = 5°K$$

SCg = 0.47 (by manufacturer)

(b) 250mm r.c. beam with glass cladding (South & East facades)



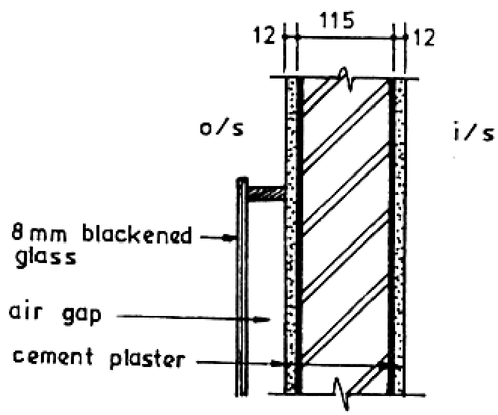
$$R = 0.044 + \frac{0.008}{1.053} + 0.16 + \frac{0.250}{1.442} + 0.12 = 0.505 m^2 \,°K/W$$

$$U = \frac{1}{R} = 1.98 W/m^2 \,°K$$

$$\text{Weight } \doteqdot 2400\, kg/m^3 \times 0.25 m = 600\, kg/m^2$$

$$\therefore TDeq = 10°K$$

(c) 115mm brick parapet with glass cladding (South & East facades)



$$R = 0.044 + \frac{0.008}{1.053} + 0.16 + \frac{0.012}{0.533} + \frac{0.115}{0.807} + \frac{0.012}{0.533} + 0.12$$
$$= 0.519 m^2 \,°K/W$$

$$U = \frac{1}{R} = 1.93 W/m^2 \,°K$$

$$\text{Weight } \doteqdot 1760\, kg/m^3 \times 0.115 m = 202\, kg/m^2$$

$$\therefore TDeq = 10°K$$

(d) 200mm r.c. wall (North facade)

same as 4.1 (c)

4.3 Tower : 5th - 25th Storeys

(a) double glazing (all facades)

same as 4.2 (a)

(b) 250mm r.c. beam with glass cladding (all facades)

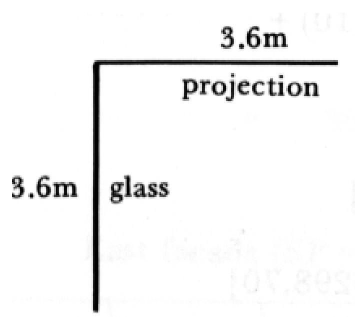
same as 4.2 (b)

(c) 115 mm brick parapet with glass cladding (all facades)

same as 4.2 (c)

5 Overhang

For 1st Storey only (South & East facades)



$$R_1 = \frac{P}{H} = \frac{3.6}{3.6} = 1.0$$

from Appendix II, Tables II(5) & II(6)

SCef = 0.67 (South)

= 0.58 (East)

6 OTTV Calculation (Alternative A)

6.1 South facade (SF = 130 x 0.74 W/m²)

$$OTTV = \frac{1}{2356.1}\begin{bmatrix}(49.5\times 2.71\times 10)+(507.5\times 1.98\times 10)+(684.4\times 1.93\times 10)+\\ 162(5.82\times 5+0.67\times 0.61\times 130\times 0.74)+952.7(2.96\times 5+0.47\times 130\times 0.74)\end{bmatrix}$$

$$= \frac{1}{2356.1}[1341.45+10048.50+13208.92+11083.54+57175.34]$$

$$= \frac{92857.75}{2356.1}$$

$$= 39.4 W/m^2$$

6.2 East facade (SF = 130 x 1.25 W/m²)

$$OTTV = \frac{1}{2114.1}\begin{bmatrix}(27.5\times2.71\times10\ )+(471.5\times1.98\times10)+(640.4\times1.93\times10)+\\90(5.82\times5+0.58\times0.61\times130\times1.25)+884.7(2.96\times5+0.47\times130\times1.25)\end{bmatrix}$$

$$= \frac{1}{2114.1}\left[745.25+9335.70+12359.72+7793.33+80662.52\right]$$

$$= \frac{110896.52}{2114.4}$$

$$= 52.46\,W/m^2$$

6.3 North facade (SF = 130 x 0.72 W/m²)

$$OTTV = \frac{1}{2053.6}\begin{bmatrix}(268.6\times2.99\times10)+(420\times1.98\times10)+(577.5\times1.93\times10)+\\787.5(2.96\times5+0.47\times0.61\times130\times0.72)\end{bmatrix}$$

$$= \frac{1}{2053.6}\left[8031.14+8316.00+11145.75+46298.70\right]$$

$$= \frac{73791.59}{2053.6}$$

$$= 35.9\,W/m^2$$

6.4 West facade (SF = 130 x 1.25 W/m²)

$$OTTV = \frac{1}{1785}\left[(420\times1.98\times10)+(577.5\times1.93.\times10)+787.5(2.96\times5+0.47\times130\times1.25)\right]$$

$$= \frac{1}{1785}\left[8316+11145.75+71800.31\right]$$

$$= \frac{91262.06}{1785}$$

$$= 51.1\,W/m^2$$

6.5 Overall for Whole Building

$$OTTV = \frac{92857.75+110896.52+73791.59+91262.06}{2356.1+2114.1+2053.6+1785.0}$$

$$= \frac{368807.92}{8308.80}$$

$$= 44.4\,W/m^2$$

6 OTTV Calculations (Alternative B)

6.1 South facade (SF = 130 x 0.74 W/m²)

Aw/Af	Uw/Uf	TDeq/ΔT	SC	(Aw x Uw x TDeq)	Af(Uf x ΔT + SC x SF)
49.5	2.71	10		1341.45	
507.5	1.98	10		10048.50	
684.4	1.93	10		13208.92	
162.0	5.82	5	0.67×0.61		11083.54
952.7	2.96	5	0.47		57175.34
2356.1				24598.87	68258.88
				92857.75	

$$OTTV = \frac{92857.75}{2356.1} = 39.4 W/m^2$$

6.2 East facade (SF = 130 x 1.25 W/m²)

Aw/Af	Uw/Uf	TDeq/ΔT	SC	(Aw x Uw x TDeq)	Af(Uf x ΔT + SC x SF)
27.5	2.71	10		745.25	
471.5	1.98	10		9335.70	
640.4	1.93	10		12359.72	
90.0	5.82	5	0.58×0.61		7793.33
884.7	2.96	5	0.47		80662.52
2114.1				22440.67	88455.85
				110896.52	

$$OTTV = \frac{110896.52}{2114.1} = 52.46 W/m^2$$

6.3 North facade (SF = 130 x 0.72 W/m²)

Aw/Af	Uw/Uf	TDeq/ΔT	SC	(Aw x Uw x TDeq)	Af(Uf x ΔT + SC x SF)
268.6	2.99	10		8031.14	
420.0	1.98	10		8316.00	
577.5	1.93	10		11145.75	
787.5	2.96	5	0.47		46298.70
2053.6				27492.89	46298.70
				73791.59	

$$OTTV = \frac{73791.59}{2053.6} = 35.9 W/m^2$$

6.4 West facade (SF = 130 x 1.25 W/m²)

Aw/Af	Uw/Uf	TDeq/ΔT	SC	(Aw x Uw x TDeq)	Af(Uf x ΔT + SC x SF)
420.0	1.98	10		8316.00	
577.5	1.93	10		11145.75	
787.5	2.96	5	0.47		71800.31
1785.0				19461.75	71800.31
				91262.06	

$$OTTV = \frac{91262.06}{1785.0} = 51.1 W/m^2$$

6.5 Overall for whole Building

$$OTTV = \frac{92857.75 + 110896.52 + 73791.59 + 91262.06}{2356.1 + 2114.1 + 2053.6 + 1785} = \frac{368807.92}{8308.8} = 44.4 W/m^2$$

APPENDIX IV FREQUENCY AND MEAN SPEED OF SURFACE WINDS IN SINGAPORE PERIOD: 1956-1971: 16 YEARS

Height of wind vane above Mean Sea Level: 21.3 metres at Singapore Airport

MONTH		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NORTH	%	46.4	35.5	20.5	7.5	4.1	2.0	1.7	1.8	1.7	6.0	17.3	37.5
	Mean Speed km/h	7.9	6.8	5.0	4.3	4.0	4.0	3.2	3.6	4.0	3.6	5.0	6.5
NORTH-EAST	%	32.9	41.4	34.6	16.5	4.1	1.5	1.1	0.9	1.2	4.1	12.0	20.4
	Mean Speed km/h	10.4	10.8	9.4	6.8	4.3	3.2	4.0	3.6	3.6	5.0	6.8	8.3
EAST	%	1.3	2.8	5.5	10.0	4.6	3.7	2.7	2.9	3.5	3.8	2.9	1.9
	Mean Speed km/h	8.6	9.5	10.1	6.8	5.4	5.0	4.3	4.3	5.0	5.8	6.1	5.8
SOUTH-EAST	%	0.6	1.0	2.4	5.0	7.7	13.3	18.6	19.3	16.7	6.3	2.3	1.0
	Mean Speed km/h	5.4	7.2	7.6	6.8	5.4	5.4	5.4	6.1	6.1	6.1	6.1	6.5
SOUTH	%	0.6	0.9	2.0	4.8	13.9	24.3	27.4	25.3	22.6	10.7	4.0	1.7
	Mean Speed km/h	5.4	7.6	6.8	7.6	7.2	8.3	8.6	9.0	3.6	7.2	7.2	7.2
SOUTH-WEST	%	0.4	0.3	1.2	2.6	7.9	7.6	6.4	6.4	6.5	7.5	3.9	1.2
	Mean Speed km/h	8.3	7.6	7.2	7.9	9.0	8.6	9.4	9.4	9.7	9.4	7.6	7.2
WEST	%	1.2	0.8	2.3	3.9	8.1	5.2	4.8	4.4	5.6	11.3	10..0	3.2
	Mean Speed km/h	8.3	6.1	6.5	6.1	7.6	7.9	7.2	7.6	7.6	7.9	7.9	6.5
NORTH-WEST	%	2.2	1.3	2.0	2.6	3.0	2.1	1.8	2.0	2.2	5.2	8.0	6.8
	Mean Speed km/h	5.4	4.7	5.0	4.3	5.0	5.4	6.4	5.4	4.7	5.0	5.8	5.4
CALM %		14.4	16.0	29.5	47.1	46.6	40.3	35.5	37.0	40.0	45.1	39.6	26.3