weight structures by purely passive means. The great temperature swing of desert climates is thus dramatically reduced.

4. The above interior temperature improvements can be further enhanced by covering the roof areas with plant growth. This is a viable approach because in the Tropics the maximum solar radiation is closer to perpendicular.

5. It has been calculated that the best thermal strategy for hot arid climates consists of planting deciduous plants on the equatorward wall. This wall should be dark coloured (high absorptance for solar radiation) to absorb maximum solar radiation when the leaves have been shed during winter.

All other walls should be covered with evergreens.

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A STUDY OF OVERALL THERMAL TRANSFER VALUES OF HIGH RISE BUILDINGS AS A GUIDELINE FOR THE DESIGN OF ENERGY SAVING BUILDING IN THAILAND

TAWEE VECHAPHUTTI
Mechanical Engineering Department
Chulalongkorn University, Bangkok 10500, Thailand

1. Introduction

The desire of energy efficient buildings is understood by all people concerned, however, the lack of Data to guide as a basis has hindered such practice in the design. In order to encourage any future building design and the retrofitting of existing buildings, the study of overall thermal transfer value (OTTV) of high rise buildings in Bangkok has been carried out. The results of OTTV values are used to compare the window to wall ratio such that simple guideline could be established.

2. Calculation of OTTV

2.1 Concept of OTTV

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.

These three elements of heat input are averaged out over the whole envelope area of the building to give an overall thermal transfer value.

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

$$OTTV = \frac{(Aw \times Uw \times TDeq) + (Af \times Uf \times \Delta T) + (Af \times SC \times SF)}{Ao} \qquad (1)$$

where

OTTV	=	overall thermal transfer value (W/m^2)
Aw	=	opaque wall area (m^2)
Uw	=	thermal trasmittance of apaque wall (W/m^2C)
TDeq	=	equivalent temperature difference (°C)
Af	=	fenestration area (m^2)
Uf	=	thermal transmittance of fenestration (W/m^2°C)
ΔT	=	temperature difference between exterior and interior design condition
SC	=	shading coefficient of fenestration
SF	=	solar factor (W/m^2)

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Ao = gross area of exterior wall
= Aw + Af

The factors, SF, SC and TDeq are evaluated for Bangkok climate using the available information of solar energy and outdoor air temperature from Ref. No. 4.

2.1.1 Solar Factor (SF)

The solar factor for vertical surfaces is derived from the annual average solar radiation transmitted through a 3 mm clear glass window (7.00 A.M. - 6.00 P.M. throughout the year) and determined for the eight primary orientations (N, NE, E, SE, S, SW, W, NW), the average solar factor for vertical surfaces has been worked out to be 130 W/m². This figure has to be modified by a correction factor when applied to a particular orientation and fenestration component having a slope angle of more than 70° with respect to the horizontal treated as a wall. For a given orientation and angle of slope, the solar factor should be calculated from the following formula:

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

Where CF is the correction factor with reference to the orientation of the facade and the pitch angle of the fenestration component given in the table 1.

Slope	NE	E	SE	S	SW	W	NW	N
90	1.08	1.29	1.38	1.43	1.52	1.46	1.18	1.00
80	1.28	1.51	1.63	1.72	1.79	1.70	1.39	1.18
70	1.48	1.72	1.88	1.98	2.05	1.93	1.60	1.38

Table 1. Solar correction factor for wall.

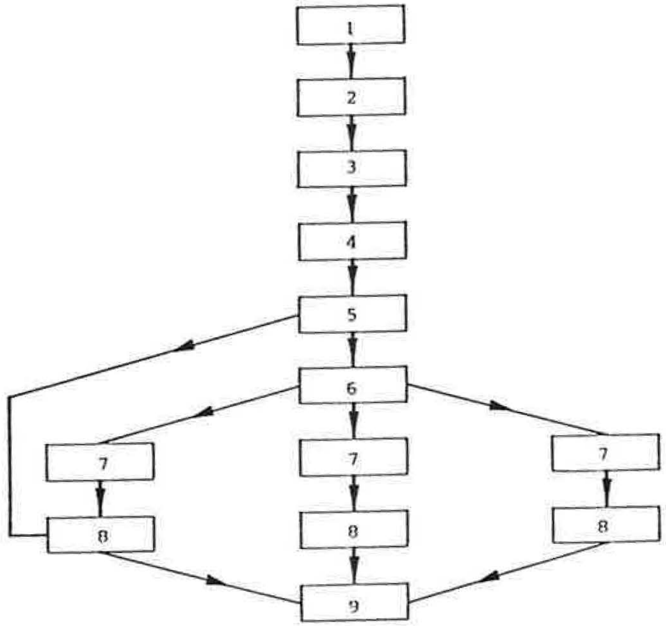
The correction factors for other orientations and other pitch angles may be found by interpolation.

In calculation, absorptance component by glass is neglected due to its small magnitude.

The flow chart in Fig. 1. shows the step of solar factor calculation for any time of day.

2.1.2 Shading coefficient

The solar factor has been derived from the annual average of solar radiation transmitted through a 3 mm clear glass window. For other system of fenestration, the rate of solar heat gain is modified by the shading



input: Date, time, location, orientation
Direct radiation, diffuse radiation, slope

1. Calculate solar time
2. Calculate hour angle from solar time
3. Calculate declination
4. Claculate zenith angle cosine
5. Calculate angle of incidence
6. Calculate radiation on plane
7. Seperate radiation on plane to direct, diffuse from sky and diffuse from ground
8. Calculate transmittance for each parts of radiation
9. Calculate total radiation by summing up each parts of radiation which transmitt through glass

Fig. 1. Flow chart showing the step of solar factor calculation

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 3 mm clear glass. This ratio is a unique characteristic of each type of fenestration system and is represented by the equation:

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

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:

$$SC = SC_1 \times SC_2 \qquad (4)$$

where

SC = shading coefficient of the fenestration system
SC_1 = shading coefficient of glass
* SC_2 = effective shading coefficient of external shading devices.

2.1.3 Equivalent Temperature Difference

Equivalent Temperature Difference (TDeq) is that temperature difference which results in the total heat flow through a structure as cause by the combined effects of solar radiation and outdoor temperature. The TDeq across a structure would take into account the types of construction, solar radiation, 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:

$$q = A \times U \times TDeq \qquad (5)$$

The technique for calculating TDeq involves the concept of sol-air temperature. Sol-air temperature is that temperature of the outdoor air which, in the absence of all radiation exchanges, would give the same rate of heat entry into the surface as would exist with the actual combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surrounding, and connective heat exchange with the outdoor air. A heat balance at a sunlit surface gives the heat flux into the surface q/A in W/m², as:

* For the purpose of OTTV calculation, the shading effect offered by internal venetian blind and curtain should be ignored.

$$q/A = \alpha I_t + h_o(t_o - t_s) - \varepsilon \Delta R \qquad (6)$$

where

α = absorptance of the surface for solar radiation
I_t = total solar radiation incident on the surface, W/m²
h_o = coefficient of heat transfer by long wave radiation and convection at the outer surface, W/m²°C
T_o = outdoor air temperature, °C
T_s = surface temperature, °C
ε = hemispherical emittance of the surface
ΔR = the difference between the longwave radiation incident on the surface from the sky and surroundings, and the radiation emitted by a blackbody at outdoor air temperature, W/m².

Assuming the rate of heat transfer can be expressed in terms of the sol-air temperature, t_e:

$$q/A = h_o(t_e - t_s) \qquad (7)$$

so

$$t_e = t_o + \alpha I_t/h_o - \varepsilon \Delta R/h_o \qquad (8)$$

For vertical surfaces that receive longwave radiation from the ground and surrounding buildings as well as from the sky so it is difficult to determine their accurate ΔR values. When solar radiation intensity is high, surfaces of terrestrial objects usually have a higher temperature than the outdoor air; thus, their longwave radiation compensates to some extent for the sky's low emittance. Because of this it is common practice to assume ΔR = 0 for vertical surfaces. For the parameter α/h_o, it is appropriate to assign a value of 0.039 for medium-colored surface.

For TDeq, it can be found by using the Transfer Function Method (TFM) which is used to compute the one-dimensional transient heat flow through various sunlit walls. The results is generalized to some extent by dividing the heat gain by the U-factor for each wall. The results thus obtained are in units of TDeq.

By TFM, the sol-air temperature represents outdoor conditions, assuming the indoor air temperature and both indoor and outdoor surface heat transfer coefficients to be constant. The equation for calculating heat gain through a wall at any time is:

$$q_{e,\tau} = A\left[\sum_{n=0} b_n (t_{e,\tau-n\Delta}) - \sum_{n=1} d_n \frac{q_{e,\tau-n\Delta}}{A} - t_{rc} \sum_{n=0} c_n\right] \qquad (9)$$

where

A = indoor surface area of a wall, m²
$q_{e,\tau}$ = heat gain by the space through indoor surfaces of a wall, watts
τ = time, hours

Δ	=	time interval, hours
n	=	summation index
$t_{e,\tau-n\Delta}$	=	sol-air temperature at time $-n$, °C
t_{rc}	=	constant indoor air temperature, °C
b_n, C_n, d_n	=	transfer function coefficients

The transfer function coefficients b and d and $\sum_{n=o} C_n$ for walls are listed in 1977 and 1981 ASHRAE Fundamentals Volumes.

For the sake of simplicity in OTTV calculation, the TDeq of different types of construction have been narrowed down to three values according to the mass of the constructions, as given in the Table 2.

Wall construction - Mass per unit area		TDeq
0 - 150	kg/m²	12 °C
151 - 351	kg/m²	8 °C
above 351	kg/m²	6 °C

Table 2. Equivalent temperature difference for walls

3. Calculation of OTTV - value for high-rise building

The OTTVs of individual walls calculated from Eq. 1, then the OTTV of the whole building envelope is obtained by applying the weight to these values. The following formula is used:

$$OTTV = \frac{A_{o1} \times OTTV_1 + A_{o2} \times OTTV_2 + \_\_\_\_\_ + A_{on} \times OTTV_n}{A_{o1} + A_{o2} + \_\_\_\_\_ + A_{on}} \quad (10)$$

Four high rise building of different envelope were studied. The architectural details of envelopes and OTTV results are shown in Table 3. The average outdoor temperature is about 30°C (average between 7.00 A.M. to 6.00 P.M. throughout the year).

4. Discussion

Among the four high rise buildings studied, three of them utilize curtain wall type construction (A, B and C) and the fourth one is with conservative design having nearly 45% glass window. Window to wall ratio (WWR) of building A and B are about 70% while building C is lower at 55%.

Considering the OTTV-values, buildings A, B and C are worked out to have the values between 85 to 92 W/m². Eventhough the WWR of building C is lower, its OTTV falls between the others due to the locking of external shading device leaving most of the glass area exposed to the sun.

For building D with conservative design having WWR of 45%, its OTTV-value is only 67 W/m².

Building	A	B	C	D
numbers of storeys	12	12	18	17
Surface-volume ratio	1:4	1:3	1:4	1:8
Void-surface ratio	1:3	1:4	1:4	1:6
Window-wall ratio	1:1.47	1:1.42	1:1.81	1:2.23
Void-floor area ratio	1:3	1:3	1:4	1:14
OTTV	85	92	90	67

Table 3. Architectural details of envelopes and OTTV results

5. Conclusion

Generally, it can be concluded that the OTTV of building envelope constructed with curtain walls are found to be between 85 to 92 W/m² while the value for conservative design building is considerably lower.

This result would give some guidances to the architects in Thailand and make them aware of the effect of different building envelope designs which bear considerable influence on the thermal comfort and sizes of air-conditioning equipment thereafter. With carefully designed building envelope, it is expecting that energy efficient buildings in Thailand could be achieved in practice.

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