

Study of the Effectiveness of Solar Heat Gain and Day light Factors on Minimizing Electricity Use in High rise Buildings

Mansour Nikpour, Mohd Zin kandar, Mohsen Ghasemi, Hossein Fallah

Abstract—Over half of the total electricity consumption is used in buildings. Air-conditioning and electric lighting are the two main resources of electricity consumption in high rise buildings. One way to reduce electricity consumption would be to limit heat gain into buildings, therefore reduce the demand for air-conditioning during hot summer months especially in hot regions. On the other hand natural daylight can be used to reduce the use of electricity for artificial lighting. In this paper effective factors on minimizing heat gain and achieving required day light were reviewed. As daylight always accompanied by solar heat gain. Also interactions between heat gain and daylight were discussed through previous studies and equations which are related to heat gain and day lighting especially in high rise buildings. As a result importance of building's form and its component on energy consumption in buildings were clarified.

Keywords—High rise buildings, Energy demand, Day lighting, Heat gain

I. INTRODUCTION

THE overall thermal transfer value (OTTV) and day lighting are two main parameters for controlling building energy use [1].

Air-conditioning and electric lighting are the two main factors for electric use in cooling-dominated office buildings [2]. Recent studies revealed that air-conditioning and artificial lighting represent 50-60 percent and 20- 30 percent, respectively, of total electricity use in buildings [3].

The OTTV is basically a measure of the heat transfer from outside to the indoor environment through the external envelope of a building. Solar heat gain through fenestration is considered as the largest provider to building envelope cooling load and the most important parameter for OTTV determinations [4].

In recent years, there has been an increasing interest in using daylight to save energy in buildings [1]. It has been pointed out that in tropical and subtropical regions, daylighting is always an energy saver [5].

Energy savings resulting from daylighting mean not only low electric lighting and reduced peak electrical demands, but also reduced cooling requirements and potential for smaller

heating, ventilating and air-conditioning (HVAC) equipment size. Daylight, however, is always accompanied by solar heat gain. An increase in the OTTV and hence cooling requirement due to a bigger glazing area could be compensated from daylight-induced energy savings. However, daylight is always accompanied by solar heat gain. When the illuminance level exceeds the design requirement, the benefits from daylight will be penalized by the increased solar heat gains which will increase the cooling load [6].

Performance of the building envelopes was investigated in terms of the overall thermal transfer value (OTTV) [7].

The OTTV is basically a measure of the heat transfer from outside to the indoor environment through external envelope of a building. Solar heat gain through fenestration is considered as the largest provider to building envelope cooling load and the most important parameter for OTTV determinations [4].

A. Overall Thermal Transfer Value (OTTV) According to ASHRAE 90A- 1980.

The OTTV concept was introduced in the ASHRAE Standard 90A- 1980. OTTV shows the average heat gain through the building envelope. Smaller OTTV cause less energy consumption for cooling. Three components of the heat gain are considered, namely conduction through an opaque surface, conduction through glass window and solar radiation through glass window. The general OTTV equation can be expressed as [8].

$$OTTV_i = (Q_w + Q_g + Q_s)/A_i = [(A_w \times U_w \times TD_{eq}) + (A_f \times U_f \times DT) + (A_f \times SC \times SF)]/A_i$$

A_f is the area of fenestration (m^2);

A_i , the gross area of the walls (m^2) = $A_w + A_f$;

A_w , the area of opaque wall (m^2);

DT , the temperature difference between exterior and interior design conditions (C);

Q_g , the heat conduction through glass windows (W);

Q_s , the solar radiation through glass windows (W);

Q_w , the heat conduction through opaque walls (W);

Mansour Nikpour is with the Department of architecture, Islamic Azad University, Bam Branch, Iran and Ph.D Candidate in Architecture Department, faculty of Built Environment, UTM, Malaysia, e-mail: mnk56@gmail.com.

Mohd Zin Kandar is with Architecture Department, faculty of Built Environment, UTM, Malaysia, e-mail: drzin2000@yahoo.com.

Mohsen ghasemi is with the Department of architecture, Islamic Azad University, Bam Branch, Iran, e-mail: mgh1393@yahoo.com.

Hossein Fallah is with the Department of architecture, Islamic Azad University, Bardsir Branch, Iran, e-mail: fallah@bardsiriau.ac.ir

Manuscript received December 31, 2010; revised January 20, 2011.

SC , the shading coefficient (dimensionless);

SF , the solar factor (W/m^2);

TD_{eq} , the equivalent temperature difference ($^{\circ}C$);

U_f , the U-value of fenestration (W/m^2K);

U_w , the U-value of opaque wall (W/m^2K).

This equation can be expressed in terms of window-to-wall ratio, WWR . Thus

$$OTTV_i = [(1 - WWR) \times TD_{eq} \times U_w] + [(WWR) \times DT \times (U_f)] + [(WWR) \times SC \times SF]$$

Where, WWR is the ratio of window area to gross wall area $= A_f/A_i$.

As walls at different orientations receive different amounts of solar radiation, the general procedure is to calculate the $OTTV_s$ of individual walls with the same orientation and construction first [8].

$$OTTV_{wall} = [A_1 \times OTTV_1 + A_2 \times OTTV_2 + \dots + A_n \times OTTV_n]/A_{tw}$$

Where,

$OTTV_{wall}$ is the $OTTV$ of the whole exterior wall (W/m^2) and

$A_{tw} = S(A_i) =$ total gross exterior wall area (m^2) [8].

It has been shown that among the three components of heat gain in the $OTTV$ equation, solar radiation through the fenestration is the most significant [4].

The building variables controlling solar heat gain are SC and window-to-wall ratio (WWR), which are two parameters in the $OTTV$ calculation. Large WWR means high Q_g and low Q_w , and vice-versa.

It should be pointed out that excluding Q_g in $OTTV$ determination may lead to an underestimation of total building envelope heat gain, particularly for curtain-walled buildings with full floor-to-ceiling height glazing. More solar heat gain contributes to more cooling requirements and hence larger air-conditioning plants [9].

Higher solar heat gain, however, could also mean more daylight available for a day lighting scheme. There is a scope for integrating daylight with electric light to save building energy use. It is argued that the increased cooling load and electricity expenditures caused from larger window areas could be offset by daylight-induced savings.

II. METHODOLOGY

In this paper all parameters that can effect on energy consumption especially heat gain through envelope were investigated with using Overall Thermal transfer value equations

based on previous research then several suggestion for reduction heat gain were represented. In addition each parameter of $OTTV$ equation were clarified and correlation between energy consumption, heat gain and daylight were contemplated to appear the effect of heat gain, day light and interaction between them on minimizing energy consumption.

III. FINDING AND DISCUSSION

It's clear for reduction energy consumption in buildings especially in high rise buildings that have much area against solar radiation, the amount of $OTTV$ (Overall Thermal Transfer Value) should be reduced.

Lam (1994) revealed that The $OTTV$ is basically a measure of the heat transfer from outside to the indoor environment through the external envelope of a building [4].

To reduce the amount of $OTTV$, Three component of $OTTV$ were investigated. Conduction through an opaque wall is one of component of $OTTV$ equation and it is considered as Q_w .

$$Q_w = A_w \times U_w \times TD_{eq}$$

A. Wall Area (A_w) and Fenestration Area (A_f)

The area of each envelope in each orientation is one of important parameters that can influence on the amount of heat conduction through opaque wall. However the area of wall depend on designing envelope and it's obvious that if the amount of A_w become less, the heat conduction through opaque wall decreases but with respect to

$$A_t = A_w + A_f$$

and A_t is a fix number. Reduction area of opaque wall means increasing the area of fenestration.

Also U-values of different types of glass such as clear, tinted and reflected glass are 6, 6.2 and 5.6 respectively. with compare to U-value of common opaque wall (30mm Concrete) with 2.4 the U-value of glass is more than U-value wall thus despite of reduction the amount of heat conduction through opaque wall with decreasing area of wall, the amount of heat conduction through fenestration and also solar radiation through glass increase.

It means decreasing the area of wall that causes increasing window area, not only does not reduction overall thermal transfer but also it causes increasing overall thermal transfer value.

In addition according to $OTTV$ equation and definition of WWR That is the ratio of window area to gross wall. It's clear that with increasing WWR the amount of $OTTV$ increase.

B. U-value of Opaque Wall (U_w) and U-value of Fenestration (U_f)

U-value of opaque wall also can effect on the amount of $OTTV$. less U-value means less heat conduction through opaque wall hence it cause the less amount of $OTTV$. External walls usually had 125 – 250mm thick concrete, mostly with mosaic/ceramic tiles applied to cement render and without any thermal insulation.

U-value ranged typically from 2.2 to $2.9\text{W}/\text{m}^2\cdot\text{K}$, depending on the thickness of concrete and the type of surface finish. If insulation materials attach to the external walls the amount of U-value decrease significantly as well.

C. Temperature Difference Between Exterior and Interior Design Conditions (DT)

As DT is the temperature difference between exterior and interior design conditions (C) and indoor average temperature is around 22°C thus the amount of DT is depend on average of outdoor temperature. If the differences between outdoor and indoor temperature become less hence the heat conduction through opaque wall become less.

D. Equivalent Temperature Difference(TD_{eq})

If the the amount of TD_{eq} decreases, the heat conduction through opaque wall decreases as well. TD_{eq} Equivalent temperature difference considers both the conduction heat gain due to the temperature difference between the indoor and the outdoor environment and the effect of solar radiation on opaque surfaces (e.g. external walls). TD_{eq} is determined as follows: [10]

$$TD_{eq} = DT + [a \times R_{so} \times \text{avg}(I_t)]$$

a is absorption coefficient of the opaque wall surface and

R_{so} is defined as outside surface resistance ($\text{m}^2\text{K}/\text{W}$) [10].

In addition these parameters depends on characteristics and way of finishing of external wall. The less a and R_{so} means less TD_{eq} hence it cause less heat conduction through opaque wall and finally less $OTTV$.

I_t is defined solar intensity falling on the surface and I_t also can effect on energy use in buildings for cooling. For reduction the amount of heat conduction through fenestration, the amount of area of fenestration, U-value of fenestration and DT have significant role. with reduction the amount of each factor of these factors, the amount of $OTTV$ decreases and vice-versa.

E. Shading Coefficient (SC) and Solar Heat Gain Coefficient ($SHGC$)

Among the three components of heat gain in the $OTTV$ equation, solar radiation through the fenestration is the most significant [4].

The building variables controlling solar heat gain are SC and window-to-wall ratio (WWR), which are two parameters in the $OTTV$ calculation. Large WWR means high Q_g and low Q_w , and vice-versa. It should be pointed out that excluding Q_g in $OTTV$ determination may lead to an underestimation of total building envelope heat gain, particularly for curtain-walled buildings with full floor-to-ceiling height glazing. More solar heat gain contributes to more cooling requirements and hence larger air-conditioning plants [11].

Solar radiation through fenestration depends on A_f , SC and CF .

The shading coefficient (SC) was the primary term used to characterize the solar control properties of the glass in windows. Although it is being replaced by the solar heat gain coefficient ($SHGC$). It is still referenced in books and product literature.

The shading coefficient (SC) is only defined for the glazing portion of the window and does not include frame effect. It represents the ratio of solar heat gain through the system relative to that through 3mm clear glass at normal incidence. The shading coefficient is expressed as a dimensionless number from 0 to 1. A high shading coefficient means high solar gain, while a low shading coefficient means low solar gain.

For any glazing, the $SHGC$ is always lower than the SC . To perform an approximate conversion from SC to $SHGC$, Multiplying the SC value by 0.87.

Window standards are now moving away from use of shading coefficient to solar heat gain coefficient, which is defined as that fraction of incident solar radiation that actually enters a building through the window assembly as heat gain. The $SHGC$ is influenced by all the same factors as the SC , but since it can be applied to the entire window assembly, the $SHGC$ is also affected by shading from the frame as well as the ratio of glazing and frame. The solar heat gain coefficient is expressed as dimensionless number from 0 to 1.

A high coefficient signifies high heat gain, while a low coefficient means low heat gain.

According to ASHRAE (2007) Fenestration solar heat gain has two components. First is the directly transmitted solar radiation. The quantity of radiation entering the fenestration directly is governed by the solar transmittance of the glazing system. Multiplying the incident irradiance by the glazing area and its solar transmittance yields the solar heat entering the fenestration directly. The second component is the inward-flowing portion of the absorbed solar radiation, radiation that is absorbed in the glazing and framing materials of the window and is subsequently conducted, convected, and radiated to the interior of the building [12].

Absorbed solar radiation, including ultraviolet, visible, and infrared radiation from the sun and sky, is turned into heat inside the absorbing material. In a window, the glazing system temperature rises as a result to some approximately equilibrium value at which the energy gains from absorbed radiation are balanced by equal losses. The absorbed solar radiation is dissipated through conduction, convection, and radiation [12].

Some heat goes outside the building, and the remainder goes inside, adding to the directly transmitted solar radiation. The magnitude of what is called the inward-flowing fraction N of the absorbed radiation depends on the nature of the air boundary layers adjacent to both sides of the glazing, including any gas between the panes of a multiple-pane glazing system [12].

N_i is often used to distinguish the inward-flowing fraction from the outward flowing fraction,

N_o . However, because only the inward-flowing fraction is used here,

the subscript i is dropped for simplicity. [12].

The concept of the solar heat gain coefficient is best

illustrated for the case of a single glass pane in direct sunlight. Let

E_D be the direct solar irradiance incident upon a single pane of glass,

T be its solar transmittance,

A be the solar absorptance and

N be the inward-flowing fraction of the absorbed radiation. In this case, the total solar gain (heat flow per unit area) q_b that enters the space due to the incident solar radiation is

$$q_b = E_D \times (T + N \times A)$$

in units of energy flux per unit area, W/m^2 . The quantity in parenthesis in Equation is called the solar heat gain coefficient (*SHGC*).

It is the fraction of incident irradiance that enters through the glazing and becomes heat gain. It includes both the directly transmitted portion and the absorbed and reemitted portion:

$$SHGC = T + NA$$

The *SHGC* is needed to determine the solar radiant heat gain through a window's glazing system. The *SHGC* for certain defined conditions of spectrum and incident angle should be included along with U-factor and other instantaneous performance properties in any manufacturer's description of a window's energy performance. Because the optical properties A and T vary with the angle of incidence [defined as the angle between the rays incident on the glazing and the normal (perpendicular) to the glazing], according to Equations, the solar heat gain coefficient is also a function of angle of incidence. [12].

Besides all parameters, *WWR* and *SC* have magnitude effect on value of *OTTV*. They are the more dominant design variables as solar radiation accounts for most of the building envelope [13].

The shading coefficient (*SC*) dominates solar gains and thus affects the peak cooling demand and energy consumption of a building.

It means if the amount of *SHGC* can be reduced if the proper strategy like external shading device or self shading strategy used for obstacle incident irradiance.

F. Solar Factor(*SF*)

Assuming standard conditions with angles of incidence of 30 or less, *SF* is equal to 0.87 times the incident solar intensity. For incident angle greater than 30, solar heat transmittance will be less than 87 percent.

This is considered acceptable because solar irradiance is relatively small when incident angle is greater than 30. Besides, *OTTV* is only an index showing the comparative energy performance of different building envelope designs.

Solar factors for the four principal orientations is different. Data for the other orientations were determined by linear interpolation between these values [10].

G. Light Transmittance(*LT*)

Light transmittance also referred to as visible light transmittance, is the visible portion of the spectrum that passes through a glazing material.

A higher *LT* means there is more day light in a space which, if designed properly, can offset electric lighting and cooling loads due to lighting. Visible transmittance is influenced by the glazing type, the number of layers, and any coating that might be applied to the glazing ranges from above 90 percent to less than 10 percent for highly reflective coating on tinted glass.

The light transmittance (*LT*) of the fenestration controls the indoor daylight availability, and offsets the electric lighting energy and cooling requirements due to sensible heat gain from the artificial lighting system. [14].

H. Solar Aperture (*SA*) and Day Light Aperture(*DA*)

Solar aperture is defined as the *WWR* times *SC*. Solar aperture indicates the proportion of incident solar that enters the zone as heat gain.

Day lighting aperture is the product of *WWR* and *LT* of the window glass and equal to *WWR* times *LT* [5].

Day lighting aperture determines the amount of daylight entering a building and it directly affects the performance of a day lighting design. [14].

I. Electricity Use

Peak electricity demand determines the maximum loads and is useful for plant and equipment sizing. Initial costs and operating strategies are affected by the maximum demands, even though building energy consumption may not be significantly affected.

Incremental electricity use is defined as the difference between the consumption with windows and the consumption without windows.

According to Li(2002) There is a correlation between between Incremental Electricity Use(*IEU*) and *OTTV*. This correlation shows the effect of heat gain on energy consumption in buildings. IEU_0 for all perimeter zones can be expressed in term of *OTTV* as follow: [14]

$$IEU_0(\text{in } MWh) = 30.7(OTTV - 30)$$

The critical variable determining the solar heat gains and the amount of daylight entering a building is the glazing area. A large window area means more cooling requirements due to an increase in solar radiation and also less electricity for lighting

two parameters, namely solar aperture (*SA*) and day lighting aperture (*DA*), were used for interaction between heat gain and day light.

There is a correlation between *PED* (Peak Electricity Use) and *SA*.

The *PED* (Peak Electricity Use) can be expressed in term of *SA* as follow:

$$PED = 2562.9SA + 4101.3(KW)$$

There is a correlation between *IEU* (Incremental Electricity Use) and *SA*.

The *IEU* (Incremental Electricity Use) can be expressed in term of *SA* as follow:

$$IEU = 4713SA(KWh)$$

Also there is another correlation between *PED* (Peak Electricity Use) and *DA*.

PED (Peak Electricity Use) can be expressed as a cubic function of *DA* as follow:

$$PED = -15.023DA^3 + 17.488DA^2 - 3889DA + 4162(KW)$$

Also there is another correlation between *IEU* (Incremental Electricity Use) and *DA*.

IEU (Incremental Electricity Use) can be expressed as a cubic function of *DA* as follow:

$$IEU = 1676(e^{-7.3DA} - 1)$$

The ratio of light transmittance to shading coefficient, is a measure of the energy efficiency of a particular glass type in terms of the day lighting potential and likely impact on cooling load [15].

Nevertheless, K_e provide an indication of the likely energy efficiency and the optimum solar and day lighting apertures [14].

The ratio of *OTTV* to *DA* (*OTTV/DA*), which modifies the ratio of *LT* to *SC*, can be used to measure the energy efficiency of a particular building envelope design in terms of day lighting potential and the likely impact on cooling energy.

The same *OTTV/DA* can be obtained with different combinations of *DA* and *OTTV*. For a fixed *OTTV/DA* value, the energy performance can vary a great deal.

This indicates that *OTTV/DA* in itself is not a sufficient parameter to determine energy performance. Nevertheless, *OTTV/DA* can provide an indication of the likely energy efficiency and the optimum *OTTV* and *DA* [1].

IV. CONCLUSION

Among a lot of parameters that can effect on energy consumption in buildings especially high rise buildings, *WWR*, *SHGC* and *LT* have important role in amount of heat and day light enter in to space of building and they have significant effect on electricity use in buildings.

There is a correlation between the annual incremental electricity use and *OTTV*, also there are correlations between *IEU* (Incremental Electricity Use) and *PED* (Peak Electricity Use) with day lighting aperture (*DA*) and *SA* Solar aperture.

Also *SA* and *DA* indicate the amount of heat gain and daylight respectively and the correlation between them and *IEU* and *PEU* shows the interaction between them.

In addition preventing solar incidence with using external shading devices or self shading strategy can intervene on *SHGC* hence *OTTV*, so these strategies play fundamental role in minimizing energy consumption in buildings especially high rise buildings. Energy savings mean not only low electric for cooling and lighting but also it causes the potential for smaller heating, ventilating and air-conditioning plants.

REFERENCES

- [1] D.H.W Li and J.C. Lam and S.L.Wong, *Daylighting and its implications to overall thermal transfer value (OTTV) determinations*, Energy, vol.27, 2002, pp 991-1008.
- [2] R. Sullivan, E.S. Lee and S.Selkowitz, *A Method of Optimizing Solar Control and Daylighting Performance in Commercial Buildings*, Lawrence Berkeley Laboratory, University of California, CA, 1992.
- [3] J.C. Lam and D.H.W Li, *Study of solar radiation data significant energy and environmental implications for Hong Kong*, Energy Conversion and Management 37, 1996, pp 343351.
- [4] J.C. Lam and C.J. Goodsall, *A survey of building envelope designs for commercial buildings in Hong Kong*, Building Research and Information 22, 1994, pp 7986.
- [5] Y.J. Huang, B. Thom, B. Ramadan, *A daylighting design tool for Singapore based on DOE-2.1C simulations*, Proceedings of the ASHRAE Far East Conference on Air-conditioning in Hot Climates, Kuala Lumpur; 1989, pp 20027.
- [6] M.A. Wilkinson, *The effect of glazing upon energy consumption within buildings*, Lighting Research and Technology, 24(2), 1992, pp 99101.
- [7] J.C. Lam et al, *Residential building envelope heat gain and coolin*, Energy, vol. 37, 2005, pp. 529-544.
- [8] American Society of Heating Refrigerating and Air Conditioning Engineers. *Energy conservation in new building design*, ASHRAE Standard 90A-1980, Atlanta, GA: ASHRAE; 1980
- [9] D.H.W Li and J.C. Lam, *Solar heat gain factors and the implications to building designs in subtropical region*, Energy and Buildings, vol.32, 2000, pp 4755.
- [10] J.C. Lam et al, *Residential building envelope heat gain and cooling energy requirement*, Energy, vol. 37, 2005, pp. 529-544.
- [11] D.H.W Li and J.C. Lam, *Solar heat gain factors and the implications to building designs in subtropical region*, Energy and Buildings, vol.32, 2000, pp 4755.
- [12] American Society of Heating Refrigerating and Air Conditioning Engineers. *Energy conservation in new building design*, ASHRAE Standard 2007, Atlanta, 2007, pp 31:36-37
- [13] D.H.W Li and J.C. Lam, *Solar heat gain factors and the implications to building designs in subtropical region*, Energy and Buildings, vol.32, 2000, pp 4755.
- [14] J.C. Lam and D.H.W Li, *An analysis of daylighting and solar heat for cooling-dominated office buildings*. Solar Energy, vol.65(4), 1999, pp 25162.
- [15] D. Arasteh, R. Johnson, S. Selkowitz, S.D. Connell, *Cooling energy savings with daylighting in a hot and humid climate*, USA: Lawrence Berkeley Laboratory, University of California, 1985.