Energy efficiency façade design in high-rise apartment buildings using the calculation of solar heat transfer through windows with shading devices

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Abstract. The architectural design orientation at the first design stage plays a key role and has a great impact on the energy consumption of a building throughout its life-cycle. To provide designers with a simple and useful tool in quantitatively determining and simply optimizing the energy efficiency of a building at the very first stage of conceptual design, a factor namely building envelope energy efficiency (K\textsubscript{hqnl}) should be investigated and proposed. Heat transfer through windows and other glazed areas of mezzanine floors accounts for 86% of overall thermal transfer through building envelope, so the factor K\textsubscript{hqnl} of high-rise buildings largely depends on shading solutions. The author has established tables and charts to make reference to the values of K\textsubscript{hqnl} factor in certain high-rise apartment buildings in Hanoi calculated with a software program subject to various inputs including: types and sizes of shading devices, building orientations and at different points of time to be respectively analyzed. It is possible and easier for architects to refer to these tables and charts in façade design for a higher level of energy efficiency.

Keywords: façade design, high-rise apartment building, building envelope, energy efficiency, sun control, shading devices.

1. Introduction

An energy-efficient building design requires a holistic approach by integrating techniques, technologies and architectural innovation. The designers need to be well equipped with design strategies including active and passive design, as well as an appropriate combination of the two concepts. It is important at first to optimize all the opportunities of passive design based on the basis of special climate conditions of the site and indoor comfort requirements, then to enhance the combination of passive and active strategies, and finally to introduce active solutions of the M&E systems.

The passive strategies practiced by architects at the concept design stage are a key factor to the energy consumption of a building through its life-cycle. This is because the building design factors are almost unlikely to change, except in case of major renovation, whereas building M&E systems can be improved and replaced relatively often and better operated by occupants so that the building will become more energy-efficient [2].

An energy-efficient design comprises three stages of which stage no. 2 is supported by smart and complex energy simulation software programs such as Open Studio, Energy Plus, eQuest, Design Builder, Simergy, Trace, etc. (Figure 1).
At present, when sketching the façades of a building at the early stage of conceptual design - stage no. 1, architects use the “shading mask” method to control direct radiation penetration into a building [14], which selects types and sizes of shading devices by hours that the windows need to be shaded completely. Therefore, this method cannot quantify the energy efficiency of the facade designed solutions. This article proposed a new building façade design method: selecting the type and size of shading devices according to the requirements of controlling solar heat (both direct and diffuse radiation) penetrated through the shaded windows that could help architects quickly quantify and optimize the energy efficiency of building envelope.

2. Recommendation of building envelope energy efficiency factor – $K_{hqnl}$

According to data from a survey on civil buildings in Hanoi, Danang and Ho Chi Minh city conducted by the Ministry of Construction and International Finance Corporation (IFC) [9], energy consumption for cooling by air conditioners makes up a major part among the energy consumption within the building and is closely related to building envelope design solutions.

In order to support an architect in façade design at stage no.1, a factor namely building envelope energy efficiency ($K_{hqnl}$) for making a quantitative assessment of cooling energy efficiency in close relation to building envelope design should be proposed.

The factor is regarded as the ratio of the reduction of heat transfer through a building envelope, or in other words, is the rate of reducing cooling load on air-conditioner systems by means of architectural design to help prevent heat transmission from the outside to the inside.

The calculation of $K_{hqnl}$ is proposed as follows:

$$K_{hqnl} = \frac{Q_0 - Q_{cn}}{Q_0} = 1 - \frac{Q_{cn}}{Q_0};$$

(1)

$$Q_0 = Q_{cs,0} + Q_{m,0} + Q_{t,0} ;$$

$$Q_{cn} = Q_{cs, cn} + Q_{m, cn} + Q_{t, cn} ;$$

(1a)

(1b)

In which: $Q_0$ – Overall heat that may transfer through the building envelope (glazing, roof and external walls) into the building in case of no shading devices for glazed windows ($Q_{cs,0}$), no special insulation for the roof ($Q_{m,0}$), and no insulation layers inside the external wall ($Q_{t,0}$);

$Q_{cn}$ – Overall heat that may transfer through the building envelope (glazing, roof and external walls) with shading devices for glazed windows ($Q_{cs, cn}$), special insulation for the roof ($Q_{m, cn}$), and ordinary or insulated external wall ($Q_{t, cn}$).

Calculation of the overall heat transfer values through certain types of building envelopes (roof, external wall and window) on a typical hot summer day in Hanoi for a high-rise apartment building - “17T10” - in Nguyen Thi Dinh street, Trung Hoa - Nhan Chinh new urban area supposing that the main facade of the 17T10 building orientate towards all eight directions (E, W, N, S, NW, NE, SW, SE) and the ratio of glazed window area to floor area ($F_{cv}/F_{s}$) could vary in five cases 1/3.5; 1/4, 1/5; 1/6; 1/7 respectively show that the percentage of heat transfer into the building (on average of three
months in hot season of Hanoi) through glazed windows makes up from 86.96% to 91.94% of the overall heat transfer into the building through the building envelope [6]. Therefore, the building energy efficiency factor "$K_{h quarantine}" of a certain high-rise apartment building depends largely on how efficient its glazing could be in terms of thermal insulation.

The most effective way of passive cooling is using shading devices for external walls, then choosing appropriate insulation glass patterns to reduce solar radiation. Thus, sun-shaded common-glass window is selected to analyze the establishment of “$K_{h quarantine}$$"$, and the formula (1) can be simplified for an approximation of “$K_{h quarantine}$$"$ in high-rise buildings as follows:

$$K_{h quarantine} = 1 - \frac{Q_{c}}{Q_{0}} = 1 - \frac{F_{c} \cdot SHGC(K_{c} \cdot S_{d} + K_{h} \cdot D_{d})}{F_{c} \cdot SHGC(S_{d} + D_{d})} = 1 - \frac{K_{c} \cdot S_{d} + K_{h} \cdot D_{d}}{S_{d} + D_{d}};$$

(2)

_in which:_ $Q_{0}$ - Overall heat transfer through glass windows without shading devices into the building.

$Q_{c}$ - Overall heat transfer through glass windows with shading devices into the building.

$S_{d}$ - Incident direct solar radiation on windows; $D_{d}$ - Sky diffuse radiation intensity on windows

$K_{c}$, $K_{h}$ - Lighting coefficient and sky diffuse radiation coefficient of shading devices.

3. Calculation of the factor “$K_{h quarantine}$$"$ for high-rise apartment buildings in Hanoi

It can be noted from formula (2) that the value of solar heat transferred (both direct and diffuse) through windows with shading devices must be calculated in order to identify the factor $K_{h quarantine}$. The intensity of solar radiation (direct – $S_{d}$ and diffuse – $D_{d}$) on-site is able to be determined from either on-site measurement data or theoretical calculation. Then, the biggest challenge to be dealt with in this case is how to determine the coefficients of both lighting ($K_{c}$) and sky diffuse radiation ($K_{h}$).

From the overview of various calculation methods for solar heat gain through glazed windows with shading devices currently applicable in Vietnam and the world, it is possible to come to the following conclusions:

- The calculation of solar radiation (direct and diffuse) through windows with either uninterrupted shading devices - horizontal, vertical as well as box-shaped - proposed by Dang P N [18] proves to be more comprehensive than other authors’ methods. Despite the same principle, Dang P N’s suggest (in 1978) is believed to come out the earliest in comparison to that of ASHARE [1], and by Chan T N [4], and it was then officially endorsed into CНиП [17]. The formula was first accepted in 1993 by ASHRAE and CНиП, then in 2008 by ISO, and most recently in 2011 by Chan T N, but the ISO’s seems to be inaccurate. The most remarkable difference between Dang P N’s formula and the others is $K_{h}$ - the hidden sky radiation coefficient from differential equation performing radiation heat exchange between the surface of shading devices and central point of a window.

- Very few studies on the calculation of solar radiation through windows with interrupted horizontal shading devices have ever been conducted. The first was carried out in 1983 by two American researchers: Yandat R F and Jones R E [16], subsequently by two Iranian scientists: Raeissi S and Taheri M in 1998 [13] and most recent was Chan T N in 2011 [4].

- There has been still no outcomes to make an easy-to-use calculation of solar heat through interrupted horizontally shaded windows.

Therefore, $K_{c}$ and $K_{h}$ for uninterrupted (both horizontal and vertical) and box-shaped shading devices could be applicable with Dang P N’s formula (see Table 1), while $K_{c}$ of interrupted horizontal shading devices is formulated and $K_{h}$ is then developed from Dang P N’s differential equation by the author.

3.1. Calculation for $K_{c}$ of windows with shading devices.
Analyzing Figure 2 and Figure 3, it can be noted that:

\[ K_{cn} = \frac{F_{cn}}{F_{cs}} = \frac{F_{cs} - F_{che}}{F_{cs}} = 1 - \frac{F_{che}}{F_{cs}} \]  

(3)

in which: \( F_{cn} \) - area of exposure surface of window;
\( F_{che} \) - area of surface of window to be shaded;
\( F_{cs} \) - area of window, \( F_{cs} = F_{cn} + F_{che} \).

Table 1. The calculation of \( K_{cn} \) for uninterrupted horizontal, uninterrupted vertical and box-shaped shading devices by Dang PN [5,18].

| Uninterrupted horizontal shading device | Uninterrupted vertical shading device | Box-shaped shading device |
|----------------------------------------|---------------------------------------|---------------------------|
| \( K_{cn,z} = 1 - \left( \frac{L_{ng}}{H} \cdot \tan h \frac{a}{H} \right) \) | \( K_{cn,z} = 1 - \left( \frac{L_{ng}}{B} \cdot \tan h \left| \frac{b}{B} \right| \right) \) | \( K_{cn,z} = K_{hn,z} \cdot K_{h,d,z} \) |

(4)    (5)    (6)

in which: \( L_{ng} \), \( L_{d} \), \( L_{ov} \) - horizontal and vertical depth of shading devices, respectively
\( a \) - distance from upper edge of a window to horizontal shading device
\( b \) - distance from side edge of a window to vertical shading device
\( \gamma \) - angle made by normal and solar radiation ray projection of a wall on horizontal ground
\( z \) - testing (measurement) point of time

For interrupted horizontal shading devices: Due to its complex form of shadow which does not just depend on the rate of outreach of shading elements to the height of a window, but also widths of window and the length of shading devices, there can be nine types of shadow as shown in Figure 4.

The author has set up nine formulas for \( K_{cn,ov,z} \) corresponding to nine different cases of shadow, and boundary conditions to determine the area of shadow for relevant use of particular \( K_{cn,ov,z} \) formula, as shown in Table 2 below.
**Figure 4.** Nine types of shadow by interrupted horizontal shading devices

**Table 2.** Nine formulas of $K_{cn}$ in correspondence to nine cases of shadow cast by interrupted horizontal shading devices

| Case | Formula | Boundary Condition 1 | Boundary Condition 2 |
|------|---------|----------------------|----------------------|
| 1    | $K_{cn,ov,1} = 1 - \left( \frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} - \frac{a}{H} \right)$ | $\frac{a}{H} \leq \frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} \leq (1 + \frac{a}{H})$ | $cL_{ov} / H \leq \frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i}$ $\leq k_b + cL_{ov} / H$ |
| 2    | $K_{cn,ov,2} = 1$ | $\frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} \leq \frac{a}{H}$ | $\frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} \leq k_b$ $\frac{cL_{ov}}{H}$ |
| 3    | $K_{cn,ov,3} = 1 - \left( \frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} - \frac{a}{H} \right)$ | $\frac{a}{H} \leq \frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} \leq 1 + \frac{a}{H}$ | $\frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} \leq k_b$ $\frac{cL_{ov}}{H}$ |
| 4    | $K_{cn,ov,4} = 0$ | $\frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} \geq 1 + \frac{a}{H}$ | $\frac{L_{ov}}{H} \frac{\text{tg} \gamma_i}{\cos \gamma_i} \leq \frac{cL_{ov}}{H}$ $\left( \frac{1}{1 + \frac{a}{H}} \right)$ |
\[
K_{m,v,z} = \frac{1}{2} \left[ 1 + \frac{a}{H} - \frac{cL_w tg_h_z}{|g|\gamma_z |\cos \gamma_z|} \right] \left( 1 + \frac{a}{H} \right) \left( \frac{|g|\gamma_z}{|\cos \gamma_z|} \right) - \frac{cL_w}{H} ;
\]

(7e)

Case 5 (shadow of point M falls into the area of M'5)

Boundary condition 1:
\[
\frac{L_m}{cL_w} + \frac{tg_h_z}{H |\cos \gamma_z|} \geq \frac{1 + a}{H} ;
\]

Boundary condition 2:
\[
\frac{tg_h_z}{H} - \frac{cL_w}{H} \leq \frac{|g|\gamma_z}{|\cos \gamma_z|} \leq \frac{tg_h_z}{H} \frac{k_b + cL_w}{H} \frac{1 + a}{H}.
\]

(7f)

Case 6 (shadow of point M falls into the area of M'6)

Boundary condition 1:
\[
\frac{L_m}{H} |\gamma_z| \geq k_b + \frac{cL_w}{H} ;
\]

Boundary condition 2:
\[
\frac{|g|\gamma_z}{|\cos \gamma_z|} \frac{a}{H} \leq \frac{tg_h_z}{H} \leq \frac{1 + a}{H} \frac{|g|\gamma_z}{|\cos \gamma_z|} \frac{k_b + cL_w}{H}.
\]

(7g)

Case 7 (shadow of point M falls into the area of M'7)

Boundary condition 1:
\[
\frac{|g|\gamma_z}{|\cos \gamma_z|} \frac{L_m}{H} \geq k_b + \frac{cL_w}{H} ;
\]

Boundary condition 2:
\[
\frac{a}{H} \frac{|g|\gamma_z}{|\cos \gamma_z|} \leq \frac{tg_h_z}{H} \leq \frac{a}{cL_w} \frac{|g|\gamma_z}{|\cos \gamma_z|}.
\]

(7h)

Case 8 (shadow of point M falls into the area of M'8)

Boundary condition 1:
\[
\frac{L_m}{H} \leq \frac{|g|\gamma_z}{H} \leq k_b + \frac{cL_w}{H} ;
\]

Boundary condition 2:
\[
\frac{a}{H} \frac{|g|\gamma_z}{|\cos \gamma_z|} \leq \frac{tg_h_z}{H} \leq \frac{a}{cL_w} \frac{|g|\gamma_z}{|\cos \gamma_z|}.
\]

(7i)

Case 9 (shadow of point M falls into the area of M'9)

Boundary condition 1:
\[
\frac{|g|\gamma_z}{|\cos \gamma_z|} \frac{L_m}{H} \geq k_b + \frac{cL_w}{H} ;
\]

Boundary condition 2:
\[
\frac{a}{H} \frac{|g|\gamma_z}{|\cos \gamma_z|} \leq \frac{tg_h_z}{H} \leq \frac{a}{H}.
\]

(7j)

Note: \( k_b = \frac{B}{H} \), or \( B = k_b H \).

The extensions of shading device to the right and left of a window (cL_w) (c can be regarded as an arbitrary factor).

The calculation of \( K_m \) has been computationally programmed based on inputs of four types of shading devices applied to eight orientations (horizontal, vertical, box-shaped and overhang) with 10 different dimensions, and it has been calculated in every five months of hot season in Ha Noi (including May, June, July, August and September). Some outcomes are going to be illustrated in Table 3 below.
Table 3. K<sub>cn</sub> at particular point of time “z” of May in Hanoi for four kinds of shading devices with L<sub>eq</sub>/H = L<sub>ov</sub>/H = L<sub>d</sub>/B = 0.5 facing Southwest

| Type of shade                                         | “z” – Point of time |
|------------------------------------------------------|---------------------|
|                                                      | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| Uninterrupted horizontal shading device               | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.124 | 0.435 | 0.672 | 0.902 |
| Uninterrupted vertical shading device                 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.55 | 0.521 | 0.456 | 0.385 | 0.299 | 0.182 | 0.004 |
| Box-shaped shading device                             | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.048 | 0.13 | 0.122 | 0.004 |
| Limited horizontal shading device                     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0.039 | 0.224 | 0.521 | 0.741 | 1 |

Notes: K<sub>cn</sub> - shown in table is determined supposing that a/H = 0.05 and b/B = 0.05; while those of limited horizontal shading devices are c = 0.5 and B/H = k<sub>b</sub> = 1.2.

3.2. Calculation of K<sub>bt</sub> for shaded windows

The coefficient of diffuse radiation over the shaded surface of a window is the ratio of diffuse radiation by unveiled sky dome to the surface of a window and that by overall visual sky dome through that window without any shading device.

\[
K_{bt} = \frac{D_{d.cn}}{D_d};
\]

in which: D<sub>d.cn</sub>: Diffusion of the radiation onto the surface of a window partially subtracted with an amount from the area protected from the sky dome by a shading device.

D<sub>d</sub>: Diffuse radiation over a window without any shading device.

Since diffuse radiation rays are centripetal, it is necessary to set the origin on window surface for the calculation of K<sub>bt</sub> (Figure 5).

Figure 5. Illustration of calculation for radiation coefficient between the surface of the shading device and the center-point O of window [18].

Based on illustration on Figure 5, it is possible to notice that: taking mid-point of the upper edge of the window as the origin “O” causes an oversized sky dome Z-Z3, while the origin “O” as mid-point of the lower edge leads to an undersized sky dome; therefore, the center point of the window is set as
point of calculation. According to [18] with the assumption that diffuse radiation is equally distributed, the calculation of $K_{bt}$ will be:

$$K_{bt} = 1 - 2\Psi_{cs-cn}$$  \hspace{1cm} (9)

in which: $1$ - coefficient of radiation by the whole sky dome on the center point of the window;

$\Psi_{cs-cn}$ - coefficient of radiation by a shading device on the center point of the window.

To obtain radiation coefficient $\Psi_{cs-cn}$, Dang P N made a ratio of differential of window’s area at the center point ($dF_{cs}$) and differential of the area of the shading device ($dF_{cn}$) as shown in Figure 5, then drew a formula as follows:

$$\Psi_{dcs-dcn} = \frac{1}{2\pi} \cotg \frac{D}{h} - \frac{h}{2\pi \sqrt{L^2 + h^2}} \cotg \frac{D}{\sqrt{L^2 + h^2}}$$  \hspace{1cm} (10)

For a limitless horizontal shade incase $D$ approaches Infinity, (6) will be: $\lim_{D\to\infty} (\cotg \frac{D}{h}) = \frac{\pi}{2}$

and $\lim_{D\to\infty} (\cotg \frac{D}{\sqrt{L^2 + h^2}}) = \frac{\pi}{2}$; Therefore the calculation of $K_{bt}$ for an uninterrupted horizontal shading device, uninterrupted vertical shading device and box-shaped shading device can be written in Table 4 below.

**Table 4.** The calculation of $K_{bt}$ for uninterrupted horizontal, uninterrupted vertical and box-shaped shading devices by Dang P N [5,18].

| Uninterrupted horizontal shading device | Uninterrupted vertical shading device | Box-shaped shading device |
|----------------------------------------|-------------------------------------|---------------------------|
| $K_{bt,ng} = \frac{1}{\sqrt{1 + \frac{4L_{ng}^2}{(H+2a)^2}}}$; \hspace{1cm} (11) | $K_{bt,d} = \frac{1}{\sqrt{1 + \frac{4L_d^2}{(B+2b)^2}}}$; \hspace{1cm} (12) | $K_{bt,bb} = K_{bt,ng} \cdot K_{bt,d}$ (13) |

The formula for $K_{bt}$ of interrupted horizontal shading devices is formulated with a differential equation by Dang P N as:

$$K_{bt,ei} = 1 - \frac{2}{\pi} \cotg \frac{D}{2} \left( \frac{k_b + cL_{ei}}{H} \right) - \frac{1}{\pi} \cotg \frac{D}{2} \left( \frac{1 + a}{H} \right)^2 \left( \frac{k_b + cL_{ei}}{H} \right)$$

\hspace{1cm} (14)

Notes: $\cotg$ is presented in degree ($^\circ$).

Values of $K_{bt}$ for four types of shading devices with 10 different horizontal and vertical depths are shown in Table 5 below.

**Table 5.** Values of $K_{bt}$ for 4 different types of shade with 10 various depth rates

| Type of shading device | Outreach ratio of shading devices ($L_{ng}/H$, $L_d/B$ và $L_{ov}/H$) |
|-----------------------|--------------------------------------------------|
|                       | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
| Uninterrupted horizontal shading device | 0.987 | 0.949 | 0.896 | 0.834 | 0.771 | 0.71 | 0.654 | 0.603 | 0.558 | 0.518 |
| Uninterrupted vertical shading device | 0.987 | 0.949 | 0.896 | 0.834 | 0.771 | 0.71 | 0.654 | 0.603 | 0.558 | 0.518 |
| Box-shaped shading device | 0.974 | 0.901 | 0.803 | 0.696 | 0.594 | 0.504 | 0.428 | 0.364 | 0.311 | 0.268 |
| Limited horizontal shading device | 1 | 0.998 | 0.997 | 0.994 | 0.992 | 0.99 | 0.988 | 0.986 | 0.985 | 0.983 |

Notes: $K_{bt}$ shown in the table is determined supposing that $a/H = 0.05$ and $b/B = 0.05$;
3.3. Calculation of the factor “$K_{hqnl}$” for high-rise apartment buildings in Hanoi

According to the research outcomes by Chan T N [3], Tuan N A [15] and Muon N V [12], the artificial cooling time in Hanoi ranges between 20% and 25% of the whole year. It is mainly in the daytime of the hot season (May, June, July, August and September). Therefore, the author has calculated the factor $K_{hqnl}$ for high-rise apartment buildings in Hanoi according to formula (1), using solar radiation data recorded hourly for 10 years (1996 - 2005), it is based on the weather data of the World Meteorological Organization’s Trace 700 software. This calculating has been carried out in the time that cooling system in Hanoi is needed (five months of hot season) supposing that the shading devices change in four different types (uninterrupted horizontal shading device, uninterrupted vertical shading device, box-shaped shading device and interrupted shading device), 10 different outreach dimensions and main façade of the building could change in eight directions. The varied-by-hour $K_{hqnl}$ can be drawn and performed in Hanoi’s five summer months in tables (e.g Table 6) or charts (e.g Figures 6, 7, 8, 9).

![Figure 6](image6.png)  
Figure 6. The variation of mean value of $K_{hqnl}$ in 5-month summer subject to eight directions by uninterrupted horizontal shading devices.

![Figure 7](image7.png)  
Figure 7. The variation of mean value of $K_{hqnl}$ in 5-month summer subject to eight directions by uninterrupted vertical shading devices.

![Figure 8](image8.png)  
Figure 8. The variation of mean value of $K_{hqnl}$ in 5-month summer subject to eight directions by box-shaped shading devices.

![Figure 9](image9.png)  
Figure 9. The variation of mean value of $K_{hqnl}$ in 5-month summer subject to eight directions by interrupted horizontal shading devices.


Table 6. Tables of $K_{h\text{box}}$ for South elevation in summer months (with $a = 0.05H$, $b = 0.05B$, while a interrupted horizontal shading device has $c = 0.5$ and $B/H = k_b = 1.2$)

| Ratio $L_{adg}/H$, $L_{adv}/H$, $L_{adg}/B$ | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
|------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|---|
| Uninterrupted horizontal shading device   | 0.029 | 0.086 | 0.153 | 0.220 | 0.287 | 0.350 | 0.405 | 0.455 | 0.501 | 0.540 |
| Uninterrupted vertical shading device     | 0.011 | 0.043 | 0.088 | 0.141 | 0.196 | 0.248 | 0.297 | 0.342 | 0.382 | 0.417 |
| Box-shaped shading device                 | 0.039 | 0.125 | 0.229 | 0.332 | 0.431 | 0.518 | 0.589 | 0.650 | 0.702 | 0.743 |
| Interrupted horizontal shading device     | 0.014 | 0.048 | 0.074 | 0.094 | 0.114 | 0.131 | 0.144 | 0.156 | 0.167 | 0.176 |

Based on the Figures 6, 7, 8, 9, it can be give some conclusions:
- The factor “$K_{h\text{box}}$” for high-rise apartment buildings in Hanoi varies considerably by time, by the direction of the building, by form and size of shading devices. Table 7 below present its average of the hot season.
- For four types of shading devices, when the dimension of shading device varies from 0.1 to 0.6, the slope of $K_{h\text{box}}$ curve is larger when it varies from 0.6 to 1.0.
- With the same dimension, the $K_{h\text{box}}$ of box-shaped shading device is the largest, assuming 100%, the $K_{h\text{box}}$ of uninterrupted horizontal, uninterrupted vertical and interrupted horizontal shading devices are 67%, 60% and 18% corresponding. Obviously the box-shaped shading device is most effective in reducing solar radiation that transfers into the building during the hot season and has the highest building envelope energy efficiency factor.

Table 7. Variability of the $K_{h\text{box}}$ on average of summer months depends on the type and size of shading devices and building orientation.

| Type of shading device                  | Outreach ratio of shading devices ($L_{adg}/H$, $L_{adg}/B$ and $L_{adv}/H$) |
|----------------------------------------|--------------------------------------------------------------------------|
|                                        | 0.3 | 0.5 | 0.8 | 1.0 |                      |
| Box-shaped shading device               | 0.292/ 0.219 | 0.507/ 0.413 | 0.71/ 0.624 | 0.791/ 0.715 |                      |
| Uninterrupted horizontal shading device | 0.176/ 0.146 | 0.315/ 0.272 | 0.482/ 0.432 | 0.561/ 0.513 |                      |
| Uninterrupted vertical shading device   | 0.208/ 0.085 | 0.324/ 0.189 | 0.486/ 0.331 | 0.567/ 0.405 |                      |
| Interrupted horizontal shading device   | 0.076/ 0.038 | 0.129/ 0.062 | 0.161/ 0.075 | 0.174/ 0.083 |                      |

Note: The above value corresponds to the direction of the building has got maximum value and the under value corresponds to the direction of the building has got minimum value.

4. Application of $K_{h\text{box}}$ in energy-efficient façade design for high-rise apartment buildings in Hanoi

Charts and tables of $K_{h\text{box}}$ can be used to determine façade features in etheir of the following two methods:

| METHOD 1                                                                 | METHOD 2                                                                 |
|-------------------------------------------------------------------------|-------------------------------------------------------------------------|
| • Step 1: Determining the value of $K_{h\text{box}}$ (for instance a façade with $K_{h\text{box}} = 0.28$ is able to reduce the total amount of heat transfer by 28%) | • Step 1: Sketching the form and façades of a building, then finding the appropriate forms of shading devices. |
| • Step 2: Sketching the form and façades of a building, then finding the appropriate forms of shading devices (such as uninterrupted horizontal shading devices for Southeast and Northeast façades as shown in Figure 10) | • Step 2: Referring to $K_{h\text{box}}$ values of each façade with corresponding shading devices in Step 1 from charts or table of $K_{h\text{box}}$ |
• **Step 3:** Referring to a value of $K_{hqnl}$ from tables or charts of $K_{hqnl}$ based on the types, then determine dimensions of shading devices on each façade. For example, determining the dimensions of shading for Southeast and Northeast elevations of an apartment block as shown in Figure 10. The angle of the shading device to be selected for Southeast facade is $\tan \alpha = L_{ng}/H = 0.44$, while that of Northeast is $\tan \alpha = L_{ng}/H = 0.46$ (Figure 11). The dimensions of the shading device may be modified as aesthetically required, or the initial shading device may be replaced and the $K_{hqnl}$ can be looked up again in the chart for optimal dimensions.

- **Step 3:** Correct the shading devices if the value of $K_{hqnl}$ is not adequate by:
  - Changing the dimensions of the shading device ($K_{hqnl}$ will then change).
  - Modifying the initial concept sketch, until an optimal value of $K_{hqnl}$ can be found.
  - Keeping the initial concept but later replacing with a new type of glass with low-SHGC factor (as a result the total cost will be higher).

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**Figure 10.** Example of a concept sketch

**Figure 11.** An illustration of how to refer to a value of $K_{hqnl}$ for uninterrupted horizontal shading device (0.28 is determined)

Here are several recommendations to optimize the shading devices when designing energy efficiency façade of high-rise apartment buildings in Hanoi based on $K_{hqnl}$ results.

- **Box-shaped shading devices**
  With small size $L_{ng}/H = 0.1$ to 0.4 and $L_d/B = 0.1$ to 0.4, the $K_{hqnl}$ is the largest in North direction. The shallow loggia or negative window solution is best in North elevation (Figure 12).

  With the size $L_{ng}/H \geq 0.4$ and $L_d/B \geq 0.4$, the $K_{hqnl}$ in Southwest direction is the highest. Shading device solution should be arranged in deep loggia or mixed style with large size in Southwest elevation.

  With the size $L_{ng}/H \geq 0.3$ and $L_d/B \geq 0.3$, the $K_{hqnl}$ in Southeast direction is high. Therefore, flexible box-shaped shading devices such as negative window, mixed style shading device, any type and size of loggia is good in Southeast elevation (Figure 13).

- **Uninterrupted horizontal shading devices**
  The $K_{hqnl}$ of uninterrupted horizontal shading device is not much different and varies in all directions equally. In addition, the horizontal style of shading devices has a good effect of rain cover and low impact on natural ventilation, which is suitable for living building in Hanoi with the characteristics of heavy rain and long drizzly time. Therefore, for energy efficient high-rise apartment
building, it is recommended that uninterrupted horizontal shading device design should be applied to windows in all directions (Figures 14).

- **Interrupted horizontal shading devices**
  The $K_{hnl}$ of interrupted horizontal shading device in the normal case ($c = 0.5$) is very low. It is therefore recommended to use interrupted horizontal shading device with large extensions ($c >> 0.5$). This device in North and South direction have negligible energy efficiency and their main function is rain cover.

- **Uninterrupted vertical shading devices**
  Uninterrupted vertical shading device is only effective in North direction with the ratio of $L_d/B = 0.1$ to $0.6$, while in other directions, the $K_{hnl}$ is lower than uninterrupted horizontal shading device and much lower than the box-shaped shading device.

![Figure 12. Example of small mixed-size shading device in North elevation](image)

**Figure 12.** Example of small mixed-size shading device in North elevation

![Figure 13. Example loggias with flexible in size and shape in Southeast elevation](image)

**Figure 13.** Example loggias with flexible in size and shape in Southeast elevation

![Figure 14: Building facade with uninterrupted and interrupted horizontal shading devices](image)

**Figure 14:** Building facade with uninterrupted and interrupted horizontal shading devices

5. **Conclusion**

The diagrams and tables representing the factor of building envelope energy efficiency ($K_{hnl}$) are expected to be useful for an energy-efficient façade design of high-rise apartment buildings in Hanoi at the stage of conceptual design, and it may offer designers a useful reference source when it comes to the designs of high-rise apartments in different parts of the Red River delta in Vietnam.

It would be also possible to introduce the factor of building envelope energy efficiency ($K_{hnl}$) and the calculation can be applied to various types of high-rise buildings in general.

**References**

1. ASHRAE Handbook – Fundamentals 2009, Inch-Pound Edition, Chapter 15. Fenestration.
2. Baker N and Steemers K 2005, *Energy and Environment in Architecture. A Technical Design Guide*. Published in the Taylor & Francis, e-Library.
3. Chan T N 2004, Research Project "Meteorological data on temperature, humidity, solar radiation to be added to the Standard of construction climate data”.
4. Chan T N 2015; Scientific base and inputs for Tables in National technical code QCVN 09:2013/Ministry of Construction – Energy efficient buildings, *Proceeding of “Urban infrastructure and sustainable urban development” conference - Vietnam Association of Civil Engineering Environment; Construction Publisher (Hanoi)*, pp. 14-24.
5. Dang P N and Ha P T 2002, *Heat and Architectural Climatics*, Construction Publisher (Hanoi), pp. 101-123; 215-222.

6. Ha P T H 2016, A Concept for Energy-Efficient High-Rise Buildings in Hanoi and a Calculation Method for Building Energy Efficiency Factor, *Procedia Engineering of the International Conference on Sustainable Development of Civil, Urban and Transportation Engineering*; Ho Chi Minh city, Published by Elsevier, Volume 142, pp 153-159.

7. Ha P T H 2016, Method of calculation solar heat penetrated through shaded windows; *Proceeding of the International Conference "Indoor air and Environmental quality"*, Published by Volgograd University; pp 232-245.

8. Ha P T H 2016, Establishing calculation formula of direct solar radiation coefficient and diffuse radiation coefficient to calculate solar heat penetrated through windows with overhang device, *Proceedings of the 17th Science and technology Conference in National University of Civil Engineering*, Construction Publisher (Hanoi), Volume 2, pp 25 – 36.

9. International Finance Corporation (IFC-WB) 2014, *Guidance on the application of National technical code QCVN 09:2013/ Ministry of construction relating to energy efficient buildings*. Ministry of Construction.

10. ISO 13790:2008 (E). Energy performance of buildings - calculation of energy use for space heating and cooling, ISO copyright office. Published in Switzerland; Geneva.

11. Ministry of Construction, National Technical Norms QCVN 09:2013/BXD on energy efficient buildings, promulgated by the Ministry of Construction in accordance with Circular No. 15/2013/TT-BXD dated 26 September 2013.

12. Muon N V 2009, Assessment of indoor comfort with Fanger's PMV and neutral temperature in contexts of Vietnam, *Conference proceeding "Occupational health caring and safety in context of Global integration"* - Vietnam National Institute of Occupational safety and health.

13. Raeissi S, Taheri M 1998, Optimum Overhang Dimensions for Energy Saving. *Building and Environment*, Vol 33, N5, pp 293-302.

14. Steven V Szokolay 2008, *Introduction to Architectural Science: The basis of sustainable design*. Architectural Press, pp 35-37.

15. Tuan N A and Reiter S 2014, A climate analysis tool for passive heating and cooling strategies in hot humid climate based on typical meteorological year data sets, *Energy and Building*. Vol 68. pp 756-763.

16. Yandat R F and Jones R E 1983. Shading effects of finite width overhang on windows facing toward the equator. *Solar Energy*, Vol. 30, No.2, pp.171-180.

17. Industrial construction project, allowance 2.91 for SNIP 2.04.05-91 "Calculation of heat radiation tranfer into the room", Lvovsky I B and Barkalov BV, Moscow 1993.

18. Dang P N and Bogolovsky V N 1978 "The calculation total heat radiation tranfer into the room through the window", *Water supply and sanitary engineering*. USSR, No1.