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A Concept for Energy-Efficient High-Rise Buildings in Hanoi and a Calculation Method for Building Energy Efficiency Factor

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Abstract

In order to quantitatively assess how energy-efficient a building can be with regard to building design, the author would like to propose an energy-efficiency factor in buildings (K_{hqnl}) and a calculation formula for this factor. The actual thermal building calculations show that 86% of the overall heat transfer in a building comes through windows. Therefore the coefficient K_{hqnl} depends largely on the sun-shading capacity of the windows that can be roughly calculated as energy efficiency factor of the window. The author will also address 6 main architectural characteristics of an energy-efficient building concept in Vietnam.

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Keywords: high-rise residential building; energy efficiency factor; heat insulation; sun shading; air conditioning

Nomenclature

AC	Air conditioning
α_t; α_m; α_k	radiation heat absorption coefficient of wall, roof or glazed surface
τ_k	radiation penetration coefficient of glass
λ_k	heat transfer coefficient of glass
t_{tg}	overall outdoor temperature for walls or roofs; $t_{tg} = t_n + \frac{\alpha.I_o}{h_n}$
t_n; t_{tr}	outdoor and indoor average temperature to be calculated
I_o	total solar radiation on wall or roof surfaces
$S_đ$	direct solar radiation intensity on windows

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D_d	sky diffuse radiation intensity on windows
SHGC	solar heat absorption coefficient of window glass, SHGC = $\tau_k + \frac{\alpha_k}{R_{o.cs} . h_n}$
$R_{o.tg}$; $R_{o.m}$; $R_{o.cs}$	total heat resistance value of walls, roofs or windows
C	covering coefficient of window transom
h_t; h_n	heat transfer coefficients (inner and outer surface of roofs and curtain walls)
K_{cn}; K_{bt}	lighting coefficient and sky diffuse radiation coefficient of sun-shading elements, as specified in documents [4, 6].

1. Introduction

Nowadays, human beings have to cope with environmental pollution, exhaustion of natural resources, energy crisis and climate change. In this context, all countries have set up national strategies towards sustainability. One of the main contents in sustainability is energy efficiency. In Vietnam, in 2013, the Ministry of Construction promulgated Standard No. QCVN 09:2013/BXD [1], in which technical specifications are required for civil building design, new construction or renovation with over 2,500 m^2 floor area in order to ensure energy efficiency.

According to the data provided by the Ministry of Construction and International Finance Corporation [2], the energy consumption in a civil building in Vietnam encompasses the following components: (1) cooling; (2) lighting; (3) electric equipment; (4) warm water; (5) elevators; (6) fans/ventilators; (7) water pumps; (8) heating. The use of air conditioning systems makes up a major part of the energy consumption (29% - 47%), then lighting, warm water, electric equipment and elevators. The energy auditing result of the office building of the Town and Country Planning Institute at No. 10 Hoa Lu street (Hanoi) conducted in 2013 revealed that air conditioning was responsible for 55% of the total energy use; lighting 17%; elevators, office equipment and other electric appliances 28%.

Architectural design is only involved with three components of the energy use, namely: (1) air conditioning for cooling or heating; (2) artificial lighting at day time, when day lighting is not sufficient; (3) warm water. The architectural design solutions to be considered include: built form, building orientation and building envelope design (sun shading, heat insulation and surface colour).

2. Recommendation of building energy efficiency factor

In order to quantitatively evaluate the energy efficiency of a building in relation to building design, a building energy efficiency factor (symbolized as *“K_{hqnl}”*) should be recommended and specified as follows:

$$K_{hqnl} = \frac{(E_0 - E_c)}{E_0} = 1 - \frac{E_c}{E_0} \quad (1)$$

$$E_o = E_{1.0} + E_{2.0} + E_{3.0}; \quad W \quad (2)$$

$$E_c = E_{1.c} + E_{2.c} + E_{3.c}; \quad W \quad (3)$$

in which:

E_0 – Total energy consumption of air conditioners ($E_{1.0}$), artificial lighting during daytime ($E_{2.0}$) and warm water supply ($E_{3.0}$), in case building design solutions do not help to reduce the heat transfer from the outside to the inside, as well as do not meet day lighting standards, and the energy for warm water is entirely provided by electricity;

E_c – Total energy consumption of air conditioners ($E_{1.c}$), artificial lighting during daytime ($E_{2.c}$) and warm water supply ($E_{3.c}$), when building design solutions are effective enough to reduce the heat transfer from the outside to the inside, as well as meet day lighting standards, and the energy for warm water is provided by solar energy.

Thus, building energy efficiency factor “K_{hqnl}” is the ratio of the total amount of energy reduction in a building with a number of building design solutions for the three purposes mentioned above to the total amount of energy consumption in that building, when no building design solutions are applied.

3. Characteristics of energy-saving and energy-efficient architecture

In consideration of the variation of the parameters in formulas (1), (2) and (3) as aforementioned and the analyses of building design solutions in Vietnam, it is possible to note that for a better energy use and a higher level of energy saving in buildings in Vietnam, a number of solutions should be applied, such as sun shading for windows and good thermal insulation for roofs in order to minimize the heat load capacity for air conditioners; good cross ventilation for buildings when comfortable outdoor climate conditions are secured in order to reduce the running time of air conditioners; appropriate window size to ensure good day lighting in order to avoid using electric light at day; external building surfaces should be painted with light colours in order to minimize solar radiation absorption; and the selection of building orientation should be made, so that the house could make use of good summer wind, avoid cold winter wind and reduce solar radiation. However, building orientation depends on urban planning, so building owners, project developers and architects cannot always choose an optimal building orientation themselves. For this reason, in order to minimize energy consumption and maximize energy efficiency in buildings in Vietnam, the following six building properties need to be taken into account [4, 5]:

- All windows in an energy-efficient building need sun-shading elements in order to minimize solar radiation that may penetrate into the building through the windows and to control glare that may cause visual discomfort. Sun shading elements for windows can be either firmly fixed or flexibly adjusted, either inside or outside windows, or between glazed windows. The glazing may be covered with a thin layer of a metallic oxide that helps to reflect the solar radiation shining straight onto the surface of the glazing. Alternatively, low-e glass may be chosen. Outer sun-shading elements can take several forms, for instance horizontal slabs, vertical slabs, fixed grid boxes, fixed or adjustable/movable horizontal slats and vertical slats, canopies, verandas, abat-vents, eaves, canvas overhangs, balconies, loggias, etc. Outer sun-shading elements do not only shelter a building better from direct sunlight, but also help to keep that building from heavy rain, without preventing wind from blowing into the building. Inner sun-shading elements, for example curtains, bamboo blinds or screens, louvres, etc. will be effective in terms of controlling indoor glare, but unable to reduce considerably solar heat penetration, because once solar radiation has penetrated into a room through glazed windows or curtain walls, it is difficult to go in the opposite direction. Low-e glass is immensely used to protect buildings from solar radiation in many countries across the globe. Low-e glass helps to filter infrared and ultraviolet rays, but the disadvantages of using low-e glass are that it does not allow natural ventilation and that this high-tech product is rather expensive.
- Floor plans should be well designed: open for natural ventilation in case outdoor climate conditions are secured and closed if necessary for air conditioning purpose. In Vietnam, except on the too hot days of the year when air conditioning systems must be activated, outdoor comfort can be easily achieved (that means the weather is neither warm nor cold). The number of comfortable days will increase from the North to the South of the country. Then, natural ventilation, when applied, will not only help to save energy for air conditioning and reduce the operation costs, but also have a very positive effect on building occupants' health. On the other hand, the building must be air-tight during the air conditioning time in order to reduce cooling loss. In high-rise buildings, natural ventilation may be horizontal (due to wind pressure) or vertical (due to wind pressure and temperature difference).
- Windows in energy-efficient buildings should be large enough and optimally arranged in order to make full use of day lighting for the entire buildings during daytime. In other words, it helps to reduce energy use for artificial lighting at day, which is of course unnecessary, because Vietnam is located in the hot humid tropical zone, where the level of sky radiation diffusion is very high. Day lighting is good for human beings, both visually and spiritually speaking.
- Solar radiation on roofs is 5 to 9 times higher than that on curtain walls. As a result, in order to reduce the solar heat transfer through the roofs that may have a negative effect on the upper floor, the roof must be as well insulated as possible, for instance with an empty space that allows air circulation underneath the roof, an insulation layer made of a light-weight material, such as mineral wool, glass fibre, straw, foam concrete, autoclaved cellular concrete, wet roof or green roof, etc. The Standard No. QCVN 09:2013/BXD [1] requires that the overall heat resistance value of the roof ($R_{0.m}$) should not be less than $1.00m^2$.K/W and the overall heat

resistance value of a wall in any direction $R_{0.tg}$ should not be less than $0.56 m^2.K/W$, so that the building will meet the latest energy efficiency standards.

- PV-panels should be installed on the roof as well as on the curtain walls to provide warm water or electricity for the building. The reality in Vietnam has already demonstrated that solar collectors can replace conventional electrical warm water tanks in high-rise building households.
- Light colour paint for external building surfaces helps to reduce the absorption of solar heat. The solar radiation absorption coefficient (α) depends on the external building paint colour. The reference document [1] suggests that the following colours with corresponding coefficients (α) should be applied: light blue $\alpha = 0.64$, cobalt blue $\alpha = 0.58$, purple $\alpha = 0.83$, yellow $\alpha = 0.44$, light colour metal sheet $\alpha = 0.26$, dark colour metal sheet $\alpha = 0.86$ and red or brown roofing tile $\alpha = 0.65 – 0.72$.

3. Building energy efficiency factor (K_{hqnl}) with air conditioning

The energy consumption survey in Hanoi, Danang and Ho Chi Minh city [2] showed that air conditioning makes up a major part in energy use in civil buildings. Therefore, in design and construction of buildings, it is essential to calculate the heat flow through the building envelope, OTTV (Overall Thermal Transfer Value, W/m^2) in order to specify the overall heat sub-loading for the air conditioning system and to assess the efficiency in terms of the energy use that a building should attain through design solutions.

For a civil building installed with air conditioning systems the energy consumption is in direct ratio to the heat transfer into the building through the building envelope. Thus, the building energy efficiency factor can be deduced from formula (1) as follows:

$$K_{hqnl} = 1 - \frac{E_c}{E_0} = 1 - \frac{Q_{cn}}{Q_0} \qquad (4)$$

$$Q_0 = Q_{cs.0} + Q_{m.0} + Q_{t.0} \text{ ; W} \qquad (5)$$

$$Q_{cn} = Q_{cs.cn} + Q_{m.cn} + Q_{t.cn} \text{ ; W} \qquad (6)$$

in which:

Q_0 – Overall heat transfer through the building envelope (windows, roof, curtain walls) into the building, when there are no sun-shading elements for windows ($Q_{cs.0}$), the roof is not specially insulated ($Q_{m.0}$), and curtain walls go without insulation boards ($Q_{t.0}$);

Q_{cn} – Overall heat transfer through the building envelope (windows, roof, curtain walls) into the building, when there are sun-shading elements for windows ($Q_{cs.cn}$), the roof is specially insulated ($Q_{m.cn}$), and curtain walls have insulation boards installed ($Q_{t.cn}$);

The calculation method is applicable to the heat transfer through the building envelope and the building energy efficiency factor (K_{hqnl}) with air conditioning. According to reference document [4] the day average heat transfer into the building through the building envelope in the summer time is specified as follows:

Heat transfer value (opaque building envelope):

$$Q_{t,m} = F \cdot \frac{t_{tg} - t_{tr}}{R_0} \text{ ; W} \qquad (7)$$

Heat transfer value through windows (without sun shading elements):

$$Q_{cs.0} = F_{cs} \cdot SHGC \cdot (S_{đ} + D_{đ}) \text{; W} \qquad (8)$$

The heat transfer value through low-e windows can also be specified with formula (8). Nevertheless, when calculating the value $Q_{cs.0}$ for low-e windows, the SHGC can be determined based on radiation penetration coefficient (τ_k) and radiation absorption coefficient (α_k) of the selected low-e glass type.

The value of radiation heat transfer through windows with fixed outer sun shading elements can be determined with the following formula:

$$Q_{cs.cn} = F_{cs} \cdot SHGC \cdot (K_{cn} \cdot S_{đ} + K_{bt} \cdot D_{đ}) \text{; W} \qquad (9)$$

The heat transfer through windows due to the difference between indoor and outdoor air temperature, whether there are sun-shading structures for windows or not, in all directions can be determined with the following formula:

$$Q_{\Delta t} = F_{cs} \cdot \frac{t_n - t_{tr}}{R_{o.cs}} \text{ ; W} \tag{10}$$

4. Experimental calculations

In order to understand more about the importance of windows and sun-shading elements for windows in reducing solar heat in buildings through building envelopes and to improve the K_{hqnl} factor, our research team conducted a survey in which the overall heat transfer values through certain types of building envelopes (roof, curtain wall and window) were separately measured on a typical hot summer day in Hanoi. By doing so, the percentage of each component in the whole could be determined. A high-rise apartment building – 17T10 building in Nguyen Thi Dinh street, Trung Hoa – Nhan Chinh new urban area (Hanoi) was selected as a case study.

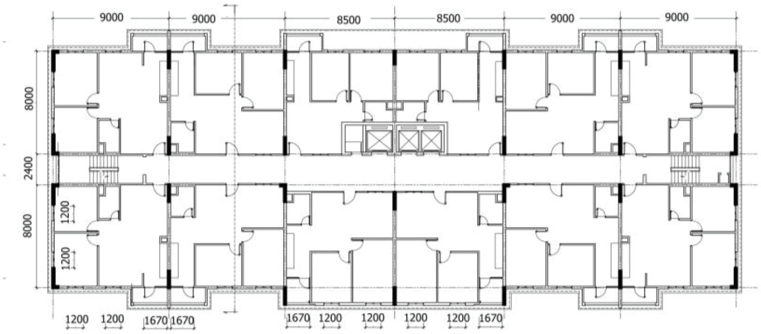
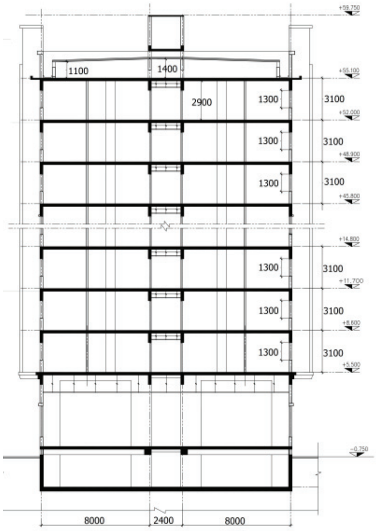


Fig. 1. Typical floor layout of 17T10 residential building



Roof structure
- Prefabricated reinforced concrete panels at 3% slope
- Reinforced concrete beams
- 200 mm reinforced concrete floor/ceiling slabs
- 15mm plastered cement mortar

Fig 2. Cross section of 17T10 residential building

Fig 3. 17T10 residential building

That is a 17 storey residential building, each storey is 3.1 m in height, and there are 12 apartments per floor. The typical floor dimension is 18.4 × 53.22 m (see Fig.1). The cross section is shown in Fig. 2 and Fig. 3 is a picture of that building.

The parameters for calculations were given as follows:

- Flat roof, $\alpha_m = 0.65$ W/m^2.K; with poor ventilated top roof floor, 1.1 m to 1.4 m high, $R_{o.m} = 0.763$m^2.K/W.

- Walls are made of two-hole baked bricks, 220 mm in thickness, with 15 mm of plastered mortar on each side, $R_{o.tg} = 0.625 m^2.K/W$; $\alpha_t = 0.42 W/m^2.K$.
- Aluminium glazed windows, the glass is 7 mm with $\lambda_k = 0.78$ W/m.K; $R_{o.cs} = 0.179\ m^2.K/W$; $\tau_k = 0.89$; $\alpha_k = 0.076\ W/m^2.K$; C = 0.82, thus SHGC value = $C\times\left(\tau_k + \frac{\alpha_k}{R_{o.cs}\times h_n}\right) = 0.82\times\left(0.89 + \frac{0.076}{0.179\times 25}\right) = 0.744$.
- Inner surface heat exchange factor for walls and windows $h_t = 7.692 W/m^2.K$; for roof $h_t = 5.882 W/m^2.K$. Outer surface heat exchange factor of building envelope $h_n = 25 W/m^2.K$.

In terms of window area: as 17T10 is a building designed for low-income residents, a low lighting standard was applied to reduce the building costs. As shown in Fig. 1 and Fig. 2, each of the two bedrooms in an apartment in the middle has only one small window 1.2 m wide ×1.3m high =1.56 m^2. In addition, there is one small window for a kitchen (0.89 m × 1.27 m = 1.13m^2) and one glazed door (0.78 m × 2.185 m = 1.7 m^2). The total window and door area of a three-room apartment is $2\times1.56\ m^2 + 1.13 m^2 + 1.70 m^2 = 5.95 m^2$, the floor area is 66.59 m^2, thus the ratio $\frac{S_{cs}}{S_{\text{sàn}}} = \frac{5.95}{66.59} = 0.0893$ or $\frac{1}{11.2}$. Normally, the ration required should be $\frac{S_{cs}}{S_{\text{sàn}}} = \frac{1}{4} \div \frac{1}{7}$. According to Chinese day lighting standard, for civil buildings in category B, the ratio will be $\frac{S_{cs}}{S_{\text{sàn}}} = \frac{1}{4} \div \frac{1}{6}$; and in Category D or E as the two minimum standards, it should be $\frac{S_{cs}}{S_{\text{sàn}}} = \frac{1}{10}$, still higher than the ratio $\frac{S_{cs}}{S_{\text{sàn}}}$ of 17T10 building ($\frac{1}{11.2}$) . For a corner apartment, there are two more windows, 1.56 m^2 each.

For this reason, while calculating for the case study, the team assumed that the main facade of the 17T10 building could change in 8 directions and that the window area on two main sides should be modified to reach the desired ratio $\frac{S_{cs}}{S_{\text{sàn}}} = \frac{1}{5}$, denoting that the total window area of each three-room apartment in the middle of the building would be $S_{cs} = \frac{66.59}{5} = 13.32\ m^2$. The windows on two gable walls remain unchanged. In this circumstance, the WWR ratio for each main facade would be $6\times\frac{13.32}{3.1\times 53.22} = 0.484$ or WWR = 48.4%.

The average day air temperature outside $t_n = 30^oC$, room temperature with air conditioning $t_{tr} = 25^oC$, total average day solar radiation intensity (I_o) on roof surface (flat roof) and on wall surfaces (windows) (W/m^2) in three summer months (June, July and August) in Hanoi might be chosen in reference to the data given by Prof. Tran Ngoc Chan [3] in Table 1 below:

Table 1. Total average day solar radiation intensity (I_o) on building surfaces (W/m^2) in Hanoi [3]

Quantity	Roof	Wall (*window*)				
		South	East and West	SE and SW	NE and NW	North
Total solar radiation (I_o), W/m^2	679.02	92.39	311.34	220.76	263.28	153.13

In application of formulas (7), (8) and (10) as presented above for overall heat transfer through the roof, walls and windows into the building in 8 directions (E, W, S, N, SE, NE, SW, NW) and in reference to the input parameters above, the research team acquired the following outcomes as seen in Table 2 for the top floor and the middle floors.

Table 2: Calculations of heat transfer through the walls, roof and windows into the building for the top floor in 8 directions

Quantity	Direction for main facade				
	South	East and West	SE and SW	NE and NW	North
Overall heat transfer through the roof (W)	25282.80	25282.780	25282.780	25282.780	25282.780
Overall heat transfer through the walls (W)	3343.372	3766.853	3677.545	3727.583	3343.372
Overall heat transfer through the windows (W)	22286.276	42941.760	35815.010	35793.136	22286.276
Overall heat transfer through the building envelope (W)	50912.428	71991.393	64775.335	64803.499	50912.428
- Percentage of heat transfer through the roof (%)	49.66	35.12	39.03	39.01	49.66
- Percentage of heat transfer through the walls (%)	6.57	5.23	5.68	5.75	6.57
- Percentage of heat transfer through the windows (%)	43.77	59.65	55.29	55.24	43.77

Table 3. Calculations of heat transfer through the walls and windows into the building for the middle floors in 8 directions

Quantity	Direction for main facade				
	South	East and West	SE and SW	NE and NW	North
Overall heat transfer through the walls (W)	3343.372	3766.853	3677.545	3727.583	3343.372
Overall heat transfer through the windows (W)	22286.276	42941.760	35815.010	35793.136	22286.276
Overall heat transfer through the building envelope (W)	25629.648	46708.613	39492.555	39520.719	25629.648
- Percentage of heat transfer through the walls (%)	13.04	8.06	9.31	9.43	13.04
- Percentage of heat transfer through the windows (%)	86.96	91.94	90.69	90.57	86.96

Remarks:

- For the top floor: The percentage of heat transfer into the building through the walls is minor, just between 5.23% and 6.57%; the percentage of heat transfer through the roof is larger, from 35.12% to 49.66% and through the windows is the largest, from 43.77% to 59.65% of the overall heat transfer into the building through the building envelope, depending on building directions. Therefore, in order to enhance the building energy efficiency factor for the top floor, it is necessary to protect the windows from solar radiation and to improve the insulation for the roof.
- For the other floors: The percentage of heat transfer into the building through the walls is minor, just between 8.06% and 13.04%; through the windows are much larger, from 86.96% to 91.94% of the overall heat transfer into the building through the building envelope, depending on building directions. Therefore, in order to enhance the building energy efficiency factor for the middle floors, it is necessary to protect the windows from solar radiation. The building energy efficiency factor “K_{hqnl}” of high-rise residential buildings depends largely on the sun-shading capacity of windows and formula (4) can be simplified as follows:

$$K_{hqnl} = 1 - \frac{Q_{cn}}{Q_0} = 1 - \frac{K_{cn}.\,S_đ + K_{bt}.D_đ}{S_đ + D_đ} \qquad (11)$$

5. Conclusion

Building energy efficiency factor “K_{hqnl}” should be proposed to evaluate how efficient a building may be in terms of energy use, as far as building design solutions are applied to a certain degree. Furthermore, the formulas to calculate the “K_{hqnl}” for high-rise apartment buildings have been established.

Based on building design solutions to be applied in relation to energy efficiency, the author emphasizes the six major features of an energy efficient buildings in Vietnam: (1) Sun shading for all windows; (2) Open apartment layout for natural ventilation and closed building envelope for air conditioning; (3) Sufficient day lighting for the entire building; (4) Good insulation for the roof; (5) Installation of PV panels on the roof and the curtain walls; (6) Light colours for external building surfaces to reduce the absorption of solar radiation.

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