Building Envelope Improvement for Energy Conservation in Office Building in Lao PDR

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Abstract: Global warming is one of the greatest problems of the world. Lao PDR is facing energy consumption problems that have been increasing rapidly. Many researchers have found that energy savings can be achieved by building envelope improvement. This research is about the impacts of building envelopes on building energy consumption. Properties of building envelopes, especially configurations of openings including horizontal fin depth, vertical fin depth and Window to Wall Ratio (WWR), that affect energy savings in a typical office building in Lao PDR, are studied. In addition, 2006 weather data collected by Lao Meteorological Department are incorporated and tested in a computer simulation program. VisualDOE4.0 program is used to simulate energy consumption with various orientations and variables. Ranges of conducted variables are horizontal fin depth of 0m—1.6m, vertical fin depth of 0m—1.2m, and WWR of 44%—65.3%. Results for all WWRs and orientations in the building, the combination of horizontal depth between 0.8m—1.2m and vertical fin depth of less than 1.0m are recommended for energy-efficient building design. In addition, there are many interesting findings in the results. They are significant because they will be used as a guideline for building designers to design building envelopes, considering the energy consumption in office buildings in Lao PDR. Moreover, the bin-formatted weather data and results can be used as a fundamental tool for Lao government's further research.

Keywords: Window to Wall Ratio, Fin design, Vientiane weather data, Energy-efficient building design, Lao architecture and energy

1. INTRODUCTION

Lao PDR is one of the countries that is affected from the global warming. The overall electricity consumption of the country in 10-year period from 1996 to 2005 increased from 379.54 GWh to 1,011.07 GWh [1]. Due to the increase in electricity consumption, Lao government as well as Ministry of Energy and Mines (MEM) forecasted electricity demand for domestic use that the rate of the electricity use will increase at 9.22% per year from 2003 to 2020. Consequently, Lao government has been establishing strategies, regulatory and law for the electricity conservation in short term and long term. The first priority focuses on the commercial and government office building at the electricity reduction of 10% per year [2]. The electricity conservation does not only depend on behaviour of people that occupies building but also depend on energy-efficient building design and building envelope improvement. Therefore, the main contribution of this research is the building envelope improvement for energy conservation in office buildings. The objectives of this paper are the estimation of energy use in typical office buildings by energy simulation, and strategies how to decrease energy use in building by considering the performance of building envelope especially configurations of windows and fins. Moreover, this research organizes and develops the weather database of Vientiane Capital, Lao PDR for future use.

2. LITERATURE REVIEW

2.1 Energy Used in Building

The major energy use in building is in a form of electricity with dynamic operations. The energy, especially electricity is consumed by four main systems—air conditioning system, lighting system, equipment (computer and office equipments) and others. Hence, the energy used in building can be expressed in equation as : energy use during a period equals to energy use for air conditioner (A/C) system + energy use for lighting system + energy use for equipment + energy use for other system [3], shown in Eq. (1).

$$En = A/C + Lighting + Equipment + Other \quad (1)$$

Energy Requirement of Air-Conditioning (A/C) System is expressed in Eq. (2) as follows:

$$A/C = \frac{CR}{COP} \times H \quad (2)$$

where En = Total energy consumption in building (kWh)
A/C = Energy consumed by A/C system (kWh)
CR = Cooling requirement (W/m^2 of floor)
H = Total number of operating hours (hour)
COP = Coefficient of performance of A/C system

2.2 Cooling Requirement (CR)

The cooling requirement is affected from two factors; external and internal factors. The external factors of cooling load are from exterior opaque wall, roof and glaze window of the building [5]. They also include loads due to air leakage into and out of the building. The internal factors of cooling loads are sensible and latent heat. Cooling requirement (*CR*) equals to the external factors of the heat gain through building envelope (overall thermal transfer value "OTTV") + internal factors (lighting, equipment, occupants ventilation and air leakage or infiltration) + thermal storage of the finite masses of walls, floors, and furniture (internal mass) [3, 4].

2.3 Influence of Building Envelope on CR

The Overall Thermal Transfer Value (OTTV) is basically a measure of the heat transfer from outside to the indoor environment through the external envelope of a building. It is an index for thermal performance of building envelopes. The OTTV equation expressed in Eq. (4) has been developed originally from ASHRAE 90-75. It was adopted for legislative controls of the building envelope designs [6, 7, 8].

$$OTTV = (TD_{eq} \times U_w)(1 - WWR) + (DT \times U_f \times WWR) + (SF \times SC \times WWR) \quad (4)$$

where DT = Temperature difference between interior and exterior (K),
SC = Shading coefficient of fenestration
SF = Solar factor of fenestration (W/m^2)
TD_{eq} = Equivalent temperature difference (K)
U_f = U-value of fenestration (W/m^2K)
U_w = U-value of opaque wall (W/m^2K)
WWR = Ratio of window area to overall wall area

Based on Lam, Hui and Chan, 1993 [7], the heat conduction through opaque wall accounts 27%, heat conduction through window glass accounts 23%, and solar radiation through window glass accounts 50% of OTTV. According to Lam, 2000 [8], he presents the cooling requirement of building envelope for generic office building. It can be noted that solar heat through the fenestration is the most significant component, accounting for about half of the building envelope cooling load. It indicates that the solar radiation through window glass influences more than the other terms. Therefore, one of factors that can reduce solar irradiance through window glass is shading coefficient (*SC*). *SC* represents configurations of windows (exterior and interior shading devices). Thus, this paper focuses on their effects on energy consumptions in typical office in Laos.

3. METHODOLOGY

3.1 Research Assumption

From the literature review, there are two important points that are more effective to the energy use in building. The first is climatic condition of location which is very important for building energy simulation. The second is characteristics of typical building especially the configuration of windows; Window-to-Wall Ratio (*WWR*) and shading coefficient (*SC*) influence on cooling requirement (*CR*) and overall energy use more than other factors in OTTV. Hence, the research assumptions can be set up as follows: 1). The research scopes only typical office building in Vientiane Capital, Lao PDR, and uses domestic materials for building envelopes (walls, ceilings, roofs, etc.). 2). The weather data of 2006 collected by Meteorological Station in Vientiane Capital, Lao PDR, is used for building energy simulation. 3). The material properties such as heat conduction of opaque walls, window glasses, ceilings, etc., are fixed, and there are no inclined walls. 4). Effect of the solar radiation reflecting from ground is neglected.

3.2 Procedure of the Research

The research is based on experiment by conducting a computer simulation process using weather data of location and characteristics of typical office building. Finding the appropriate configurations of building envelopes (window configuration) implemented a building energy simulation called "VisualDOE4.0". Fixed values of variables U_w and U_f, and varied SC values depending on exterior shade and interior shade of building are studied. Then, the results of energy simulation of each case are compared to result of base case to determine the appropriate configuration of window. The methodology for building energy simulation is presented in Fig. 1.

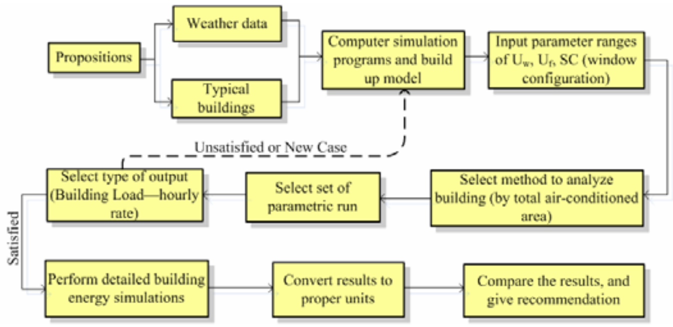

Fig. 1: Procedure for Energy Simulation and Building Envelope Improvement

3.3 Configurations of Base Case Office Building

The configuration of base case office building is the government office building in Lao PDR. It is moderately long comparing their width (W) and length (L). The width to length ratio (W/L) of building falls between 1/6 to 1/3. The reference building is 1/4 of width to length ratio, located in Vientiane Capital and has site parameters which are summarized in Table 1. Building plan is rectangular shape and symmetry that has dimension of 10 metres width, 40 metres length and 4 floors. Each floor is 3.5m height where the adiabatic plenum height is 0.5m as shown in Fig. 2. The functions of spaces inside the building have been utilized as office spaces from 8:00a.m to 17:00p.m, Monday to Friday for 2008 hours per year. The lighting system is considered general lighting system. Air-conditioning system is unitary system (split type), and equipments in building almost are computers, telephone, fax, photocopy machine, etc.

Table 1: Geological Data of Location

Items	Values	Units
Location	Vientiane Capital	---
Latitude	17.970	°N
Longitude	102.61	°E
Time zone	-07:00	hours
Azimuth of building	0.000	°S
Altitude	+162.0	m
Wind velocity (2006)	1.3	m/s
Temperature (2006): Max./ Min.	37.50 / 11.50	°C
Relative Humidity (2006)	75	%

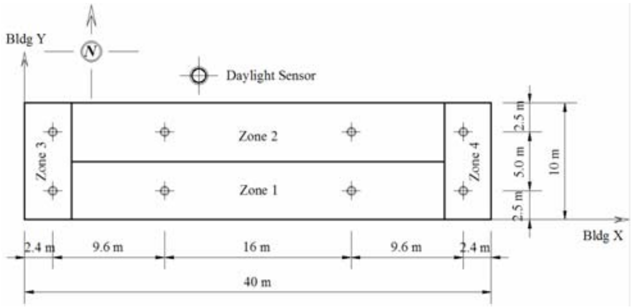

Fig. 2: Configuration of Base Case Office Building

3.4 Building Energy Simulation and Parameter Ranges

This research focuses on finding appropriate configuration of the window for energy-efficient office building design in Lao PDR. The parameters U_w, U_f, *LPD*, *EPD*, and *OCCU* are fixed value, and for the rest of *SC* values, they are varied by the window size, condition of the shading device, time and orientation of the building. The parameters that are used for simulating building energy have the ranges as expressed in Table 2, and the configurations of the windows are summarized in Table 3 and Fig. 3.

Table 2: Parameters and Values for Building Energy Simulation.

Items	Values	Units
U-value of opaque wall, U_w	1.511	W/m^2K
U-value of glass, U_f	6.172	W/m^2K
U-value of aluminium window frame	3.037	W/m^2K
Internal shading coefficient of glass	0.95	
Lighting Power Density, LPD	10.3	W/m^2
Equipment Power Density, EPD	10	W/m^2
Occupancy Density,	0.1	People/ m^2
Illuminance level at work plane level	400	lux

Table 3: Window Configurations for Building Energy Simulation.

Items	Ranges	Units
Horizontal fin Depth	0—1.6	m
Vertical fin depth	0—1.2	m
Sill height of window	0—0.8	m

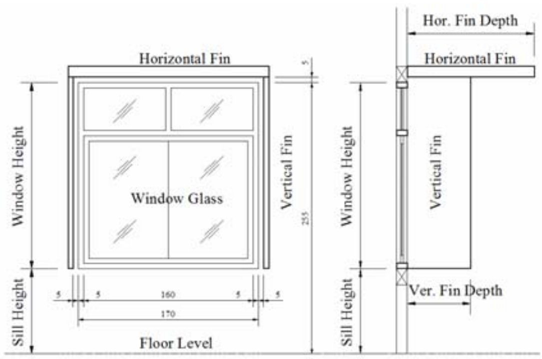

Fig. 3: Configuration of Window

In this research, the increment depth of horizontal fin is 0.4m and 0.2m for the depth ranging of 0—1.2m, and 1.2m—1.6m, respectively. The increment depth of vertical fin is 0.2m for depth ranging of 0.4m—1.2m. The decrement sill height of window is 0.2m for sill height ranging 0.4m—0.8m, and 0.4m for sill height ranging lower than 0.4m. Therefore, horizontal fin depth of 0, 0.4m, 0.8m, 1.2m, 1.4m, 1.6m, vertical fin depth of 0, 0.4m, 0.6m, 0.8m, 1.0m, 1.2m, and sill height of window of 0.8m (WWR=44%), 0.6m (WWR=49.3%), 0.4m (WWR=54.7%), 0 (WWR=65.3%) are studied for one orientation of building.
The original window size including thickness of frame is 1.7m of width, 1.75m of height, and its frames are aluminium. In order to simplify the model of window for energy simulation, the frame is assumed that has only edge frame and middle frame are neglected. The building is rotated clockwise every 15 degrees from 0—360 degrees. One zone represents one space and each zone is controlled by one system of air-conditioning system with fixed air-conditioning schedules. The numbers of zones used for simulation are 16 zones (4 zones per floor) as shown in the Fig. 2. Two daylight sensors are set at 400 lux of the illuminace level and installed at 1.0m of work plane level in each zone. The fraction of lights that are dimmed or turned off is 0.5 when lighting levels in the space exceed the design illuminance level.

4. RESULTS AND DISCUSSION

4.1 Effects of Fins on Lighting System

The fins affect the energy use for lighting system because they block daylight transmission from outside into inside the building. Then, the electric lighting system is taken place the daylighting for increasing illuminace level in building, and thus the energy use in building increases by light.

Horizontal Fin (HF) and Lighting System

For all orientations of the building, the horizontal fin depth affects the energy use for lighting system. Fin depths of greater than 0.8m create more use in lighting energy for WWR which is less than or equals to 54.7%. Fin depth of 1.2m affects energy use in lighting for WWR that is higher than 54.7%. From Fig. 4, the horizontal fin depth effects fairly constantly to the energy use for lighting system when it is among 0.8m—1.4m in case of WWR less than or equals to 44%. Fin depth of 1.2m—1.6m yields more energy in lighting system for WWR among 49.3%—54.7%, and 0.4m—1.2m for the otherwise. Consequently, the horizontal fin depth which is the best for the lighting system should not be higher than 0.8m for WWR less than or equals to 54.7%, and 1.2m for WWR higher than 54.7%.

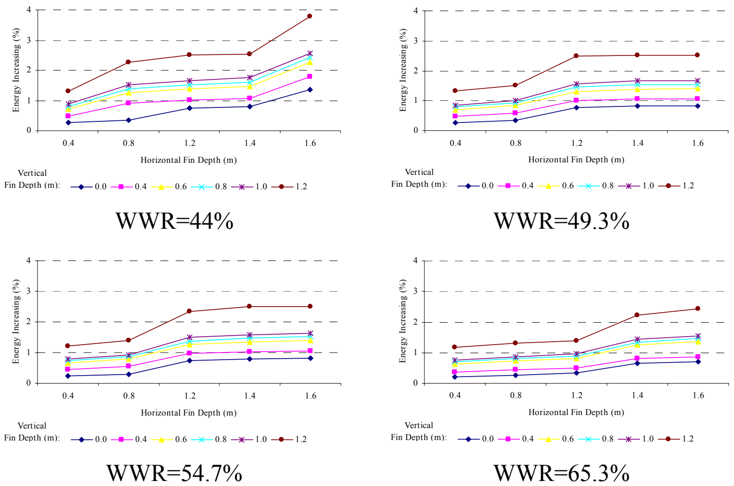

Fig. 4: Energy Increasing for Lighting System Functions HF Depth (Az=0°N)

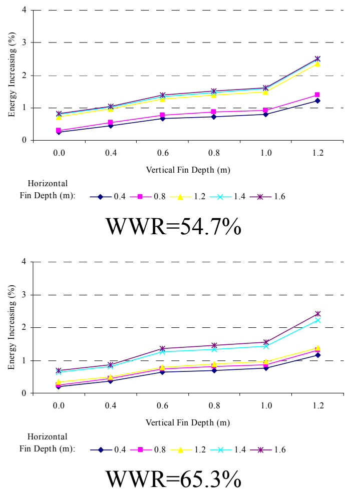

Fig. 5: Energy Increasing for Lighting System Functions VF Depth (Az=0°N)

Vertical Fin (VF) and Lighting System

The depth of vertical fin has a direct effect on the energy use for lighting system. Similar to horizontal fin, it will reduce illumance level of daylight in building. The depth of vertical fin affects the energy use for lighting system linearly associated by depth when it does not exceed 0.6m. It creates more use in lighting system quite constantly when it is among 0.6m—1.0m, and higher use in energy in lighting system when it exceeds 1.0m as shown in Fig. 5. Therefore, the vertical fin depth which is the best for lighting system should not be greater than 1.0m for all cases.

4.2 Effects of Fins on HVAC System

Although fins block daylight transmission, and they cannot save energy use in building for the lighting system but they can dramatically reduce heat gain in building. This section presents how fins affect energy use in HVAC system.

Horizontal Fin (HF) and HVAC System

The results of building energy simulation in Fig. 6 found that, for the window within horizontal fin only, the horizontal fin depth among 0.8m—1.2m is more effective because energy saving is more effective than other cases. This can be noticed by its steeper slope in the graphs. If the horizontal fin depth exceeds 1.2m, the steepness of energy saving is quite less than the case of the horizontal fin depth of 0.8m—1.2m but it can still save energy for HVAC system more than case of 0.8m—1.2m. The greater depth is more energy saving in HVAC system. In case of the window within horizontal fin and vertical fin, the depth of horizontal fin among 0.4m—1.2m is more effective than other cases as presented by steeper slopes. If the horizontal fin depth exceeds 1.2m, slope of energy saving graph is less than case of the depth among 0.4m—1.2m, similar to the previous case. Moreover, it is proportion with its depth, and it can still save energy for HVAC system more than case of horizontal fin depth of 0.4m—1.2 m.

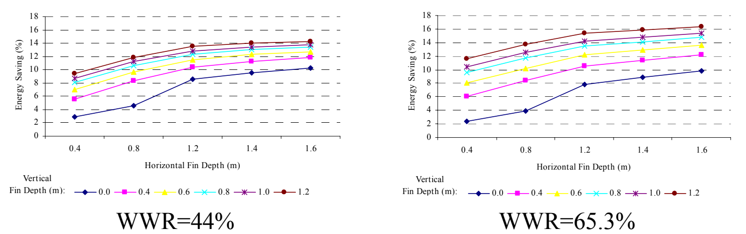

Fig. 6: Energy Saving from HVAC System Functions HF Depth (Az=0°N)

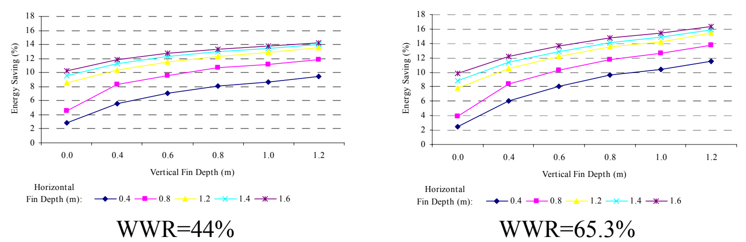

Fig. 7: Energy Saving from HVAC System Functions VF Depth (Az=0°N)

Vertical Fin (VF) and HVAC System

The vertical fin depth influences to the energy saving for HVAC system similar to horizontal fin. Fig. 7 indicates that the most effective on energy saving by vertical fin occurs when the vertical fin depth does not exceed 0.4m. When the fin depth is longer than 0.4m, the steepness of the slope on energy saving is quite less than case of fin depth 0.4m, but it can still save energy for HVAC system more than case of vertical fin depth 0.4m. It is proportion with increment depth.

4.3 Effects of Fins on Total Energy Use

The total energy saving is a combination of energy increasing for lighting system and energy saving from HVAC system. The results of combination in Fig. 8 indicate that the most effective depth of the horizontal fin is among 0.4m—1.2m in case of horizontal fin and vertical fin combine together. The most effective fin depth is among 0.8m—1.2m for case of window within horizontal fin only. When the depth of horizontal fin exceeds 1.2m and WWR exceeds 44%, the total energy saving is increased linearly with low rate, and the increasing rate is proportionally with increment depth of horizontal fin. For the WWR equals to or less than 44%, the total energy saving will be fallen down if the depth of horizontal fin exceeds than 1.4m.
Similar to this, the most effective depth of vertical fin does not exceed 0.4m because the steepness of slope of energy saving is the greatest. If the depth of vertical fin is increased from 0.4m—1.0m, the slope of energy saving is quite less than other cases. However, it can still save total energy more than the case of vertical fin depth of 0.4m, and it is a proportion with increment depth of vertical fin. The total energy saving is quite constant and may be fallen down if the depth of horizontal fin exceeds 1.0m as shown in Fig. 9.

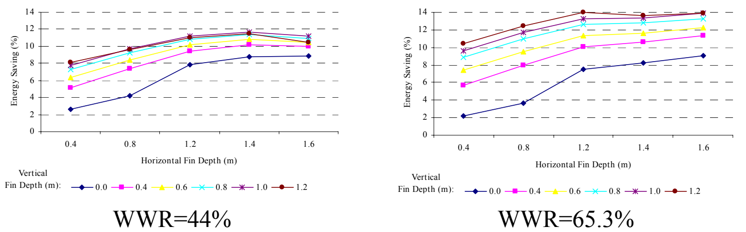

Fig. 8: Total Energy Saving Functions HF Depth (Az=0)

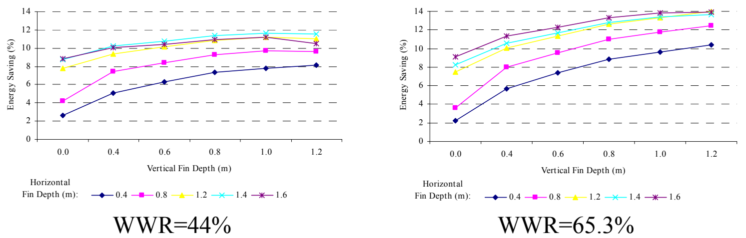

Fig 9: Total Energy Saving Functions VF Depth (Az=0°N)

4.4 Effects of Building Orientation on Total Energy Saving

The building orientation also affects to the energy saving of building. It means that the depth of horizontal fin and vertical fin are also affected. The results of the research found that the horizontal fin and vertical fin are the most effective for saving the energy use in building if the building faces to the North, East, South and West respectively (front azimuth=0°N, 90°N, 180°N and 270°N). The effectiveness of horizontal and vertical fin depth are at the greatest if the building faces north. Moreover, their effectiveness is at the lowest if the building faces to 45°N and 225°N. In addition, the results indicate that the most effective depths of horizontal and vertical fin are among 1.2m—1.6m, and 0.8m—1.2m, respectively, for all WWRs as shown in Figs. 10—11.

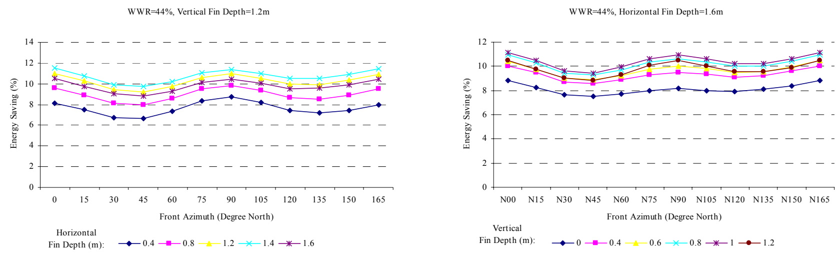

Fig. 10: Total Energy Saving Functions Front Azimuth of Building for WWR=44%

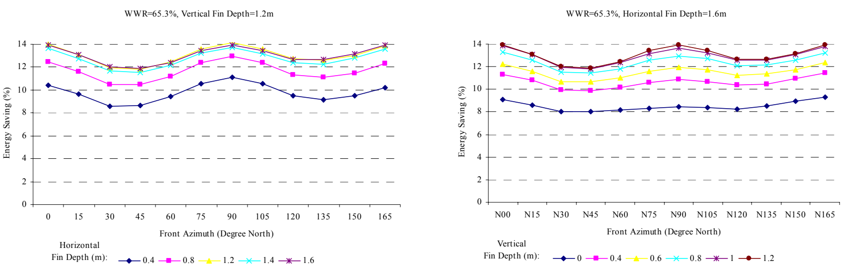

Fig 11: Total Energy Saving Functions Front Azimuth of Building for WWR=65.3%

4.3 Summary of the Research Results

According to the results discussed above, the effective depth of horizontal and vertical fin can be summarized in Table 4. This table can be used as a design decision tool for designers in making decision when they design and develop office buildings.

Table 4: Effective Depth of the Horizontal and Vertical Fin

System	WWR (%)	Horizontal Fin Depth (m)	Vertical Fin Depth (m)
Lighting	44—54.7	≤ 0.8m	≤ 1.0m
	> 54.7	≤ 1.2m	≤ 1.0m
HVAC	≥ 44.0	≥ 1.2m	≥ 0.4m
Total	≤ 44.0	<1.2m	≤ 1.0m
	> 44.0	≥ 1.2m	≤ 1.0m

4. CONCLUSIONS AND RECOMMENDATIONS

After the achieving of the research about the authors can summary the conclusion as follows: 1). Increment depth of horizontal fin and vertical fin affect to energy use for lighting system but they are better for energy use for HVAC system. 2). Increment Window to Wall Ratio (WWR) can save energy use for lighting system but energy use for HVAC system is increased. 3). The horizontal and vertical fin that effect total energy use do not exceed 1.2m and 1.0m, respectively, if WWR less than 44%. When WWR exceeds 44%, the horizontal fin depth can be longer than 1.2m but should not be longer than 1.6m because it will destroy aesthete of building. Vertical fin depth should not exceed 1.0m. 4). The effectiveness of horizontal and vertical fin will be the best for total of energy saving if the building faces to the North, East, South and West (front azimuth=0°N, 90°N, 180°N and 270°N, respectively). They will be low effectiveness if building faces to out of these directions. Their effectiveness will be at the lowest if building faces 45°N and 225°N. 5). The horizontal fin (HF) is needed for all window azimuth, and the vertical fin will not be needed if window faces to the North (0°N), North-East (45°N), and South (180°N).

5. FURTHER STUDIES

Although this research responds to the Lao government policy but it covers only some parts. Therefore, this research must be conducted with other related variables in order to study the performances of the other building envelopes. Base on the conclusions, recommendations for further studies are as follows: 1). Model of the building in energy simulation should be modelled based on the existing building such lighting power density (*LPD*) and the equipment power density (*EPD*) should be measured from the real situation. 2). Window configurations should be studied in many options such as horizontal fin may be inclined and vertical fin may not be normal to window plane in order to get more effective to block direct sun light. 3). For getting more outside view, window to wall ratio (WWR) does not only increase by increasing window height but it can be increased by increasing window width. The effect of this case should be studied. 4). Building envelope improvement is not only window configuration that needs to be improved but opaque wall and window material also need to be improved. 5). The office buildings are not in Vientiane Capital only. Buildings in other locations should be conducted to study the appropriate building envelope configurations. 6). The weather data for building energy simulation should be updated and use data of multi years to obtain more accurate simulation results.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] DOE, 2006, Electricity Statistic of Lao PDR 2005, Ministry of Energy and Mines, pp. 24—38.
[2] EE&C-SSN, 2006, Draft Report of the Tenth Meeting of the Energy Efficiency and Conservation Sub-sector Network of the ASEAN Energy Cooperation, Available: http://www.aseanenergy.org [2007, July 2].
[3] Chirarattananon, S., and Taveekun, J., 2004, "An OTTV-Based Energy Estimation Model for Commercial Buildings in Thailand", Energy and Buildings, Vol. 36, pp. 680—689.
[4] Mettanant. V., 2003, Development of OTTV Base Energy Estimation Model for Energy Management in Building, Master, Engineering, School of Environment, Resources and Development, Asian Institute of Technology.
[5] Chirarattananon, S., 2005, Building for Energy Efficiency, Scholl of Environment Resources and Development, AIT, pp. 13—27.
[6] Hui, S. C. M., 1997, "Overall Thermal Transfer Value (OTTV): how to improve its control in Hong Kong", In Proc. of the One-day Symposium on Building, Energy and Environment, 16 October 1997, Shangrila Hotel, Kowloon, Hong Kong, HKIE BS Division/CIBSE/ASHRAE/PolyU, pp. 12-1 to 12-11.
[7] Lam, J.C., Hui, S.C.M., and Chan, A.L.S., 1993, "Overall Thermal Transfer Value Control of Building Envelope Design part 2—OTTV parameters", Hong Kong Engineer, Vol. 21, pp. 27—31 & 40—41.
[8] Lam, J. C., 2000, "Energy Analysis of Commercial Buildings in Sub-tropical Climates", Building and Environment, Vol. 35, pp. 19—26.