

ENERGY AUDITING METHODOLOGIES AND INSTRUMENTATION ON SPECIAL WINDOW DESIGNED FOR SAVING ENERGY IN AIR-CONDITIONING BUILDING

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1. INTRODUCTION

One of the characteristics of modern architecture is the wide spread use of glazing in the building facades. This, the increasing use of lightweight structures has caused considerable changes in the relationship between interior and ambient atmosphere, and also the problem of overheating has become a major concern even in temperate countries.

Thermal effect of transparent building materials can be considered from two points of view; the actual heat gain of the interior space is important for calculations of cooling load in air-conditioned buildings, while the resulting indoor temperatures are more significant to comfort in rooms without mechanical forms of heat control. The functional requirements for solar control differs widely with regional climates and within each region, with seasonal climatic variations.

The unique property of glass, and some transparent plastics, which is responsible for their specific thermal effects, is the differential transparency to shortwave and longwave radiation. While transmitting most of the radiation in the range of 0.4-2.5 microns, which approximately coincides with the range of the solar spectrum, glass is

completely opaque to radiation of longer wavelength, around 10 microns.

When the shading is internal, in the form of a venetian blind for instance, solar radiation is transmitted through the glass before interception. The radiation absorbed into the shading material is rereleased to the room and almost all of this heat remains within the space as the opaqueness of the glass prevents longwave radiative heat dissipation. Only the radiation reflected outwards from the shading at the original wavelengths is transmitted in part to the exterior (some is reflected back by the glass and absorbed) and has no internal heating effect. The effectiveness of internal shading is therefore determined by its reflectivity, and on the whole is much less than that of external shades.

2. PRINCIPLE OF THE VENTILATED WINDOW

In an air-conditioned room, the provision of outside air to air-conditioned space is about 13 m³/h per person. Part of the substituted air is evacuated at room temperature (22-25°C). An extra energy from the air conditioner is used during air circulation and is considered as an energy loss. Another

loss is due to the solar energy insulating directly on the glass.

To reduce the air-conditioner power consumption, a ventilated window has been designed. It consists of two glazings separated by a ventilated air space. A venetian-type of blind painted in white to reflect some solar energy is placed in the air space. Radiative and conductive heat, absorbed by the blind, are evacuated by the cooled air flowing at low speed between glasses. Therefore, the air acts as a buffer between external and internal window panes and it prevents solar heat from entering the room. Such a window is characterized by 3 factors:-

1. Balance of thermal exchanges between exterior and interior of the buildings.
2. Solar protection.
3. Mass transfer of air per square meter and per hour.

In a tropical country like Thailand, the ambient temperature is between 25 to 35°C. Most offices and new buildings are air-conditioned at 22-24°C with an additional amount of glass doors and window panes.

This kind of window has been applied to office buildings in Europe, Sweden and North America for heating buildings but has not been studied in hot climatic countries for cooling buildings.

3. OBJECTIVE AND SCOPE OF STUDY

The principle objective of this study is to test the ventilated window for reducing the air conditioning load requirement in the buildings. The other proposition related to the above are:-

1. To improve the efficiency of the system by varying the blind position.
2. To improve the system studied.
3. To study a short economic analysis based on analysis of capital and running costs of an actual office building.

4. TEST FACILITIES

4.1 CONSTRUCTION OF THE TEST-HOUSE

A one-room house, or solar test-house, had been constructed and experimented. This facility has a standard size of 2.83m × 2.83m × 2.575m high, a volume of 20.6 m³ and 8 m² floor area. The size of this room is a compromise between the experimental needs and the real conditions for a building project.

The structure is composed of removable panels (window of wall) on three facades (East-South-West). Each one can be equipped with a complete wall, a standard window or a ventilated window.

To obtain a good insulation coefficient and low inertia, the walls are made of asbestos cement, polyester and gypsum board. The framework is of wood. Fibre glass has been used for the roof and the subfloor to increase the insulation.

4.2 DESIGN OF THE VENTILATED WINDOW

The air flow window is an arrangement of a double glazing and a space through which the air flows. A venetian blind is placed outside or in-between the glasses. Hence, it is a double glazed window with air flow over an enclosed blind. Air can be flowed in a variety of modes depending upon the design of the window. For this design involves either flow upward or flow downward. The air can be exhausted to the outside or it can be returned to the air-conditioned room. The design of ventilated window having cross-section view is illustrated in Figure 1.

Figure 1. shows the cross-section dimensions of the ventilated window with four possible ways of air flow. A venetian blind can be placed internally between double glazing air space of 5.8 cm wide. It can be adjusted from inside the room. A metallic sheet of 83.5 × 3.5 sq. cm fixed on the outer wooden frame is partially covering two-thirds of the lower portion of air space channel in order to push the air flow on the inside glass.

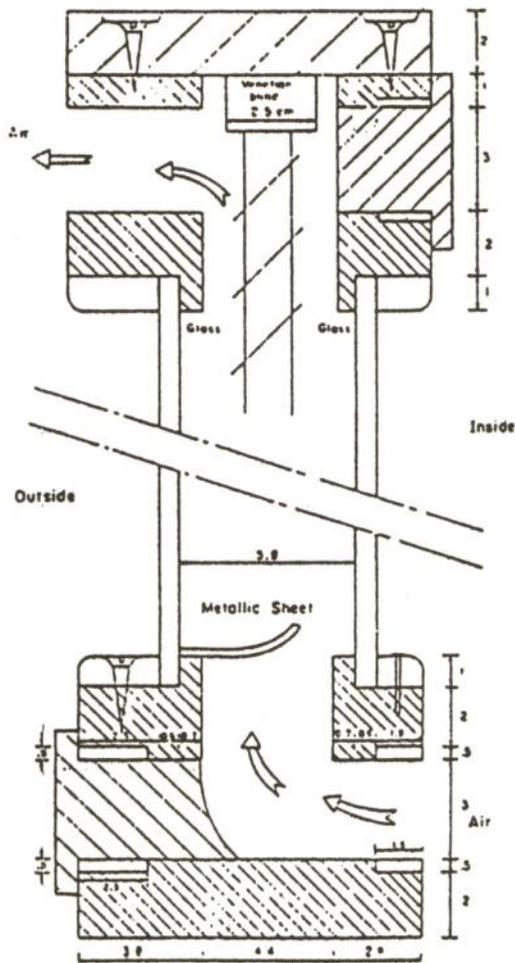


Fig. 1 Ventilated Window Cross Section View.

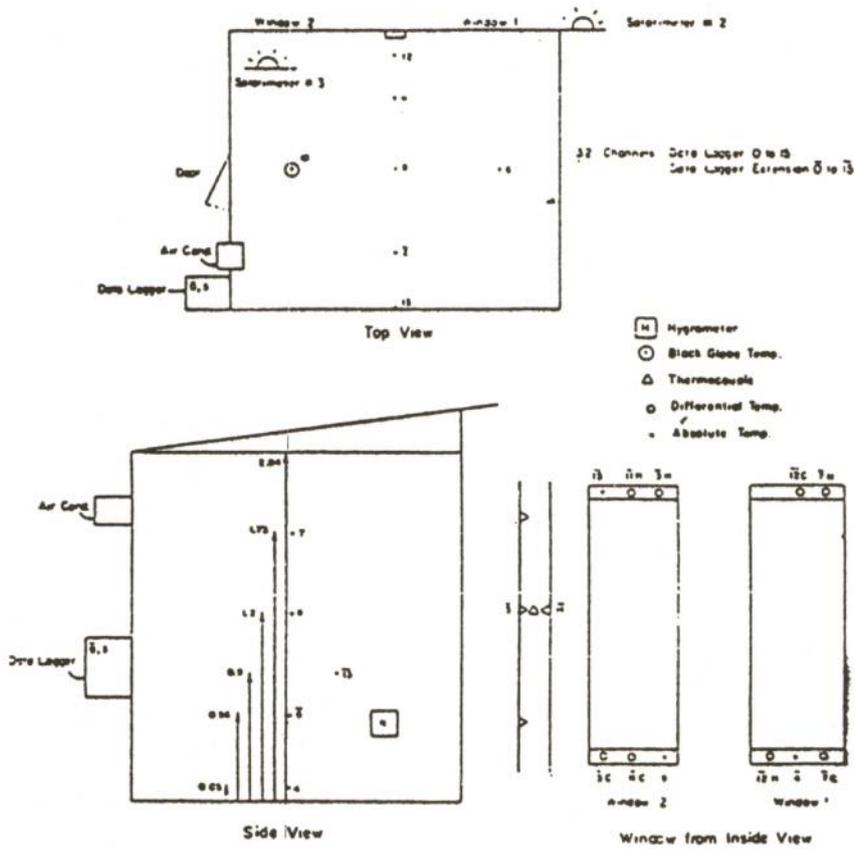


Fig. 2 Sensors Distribution in the Test House

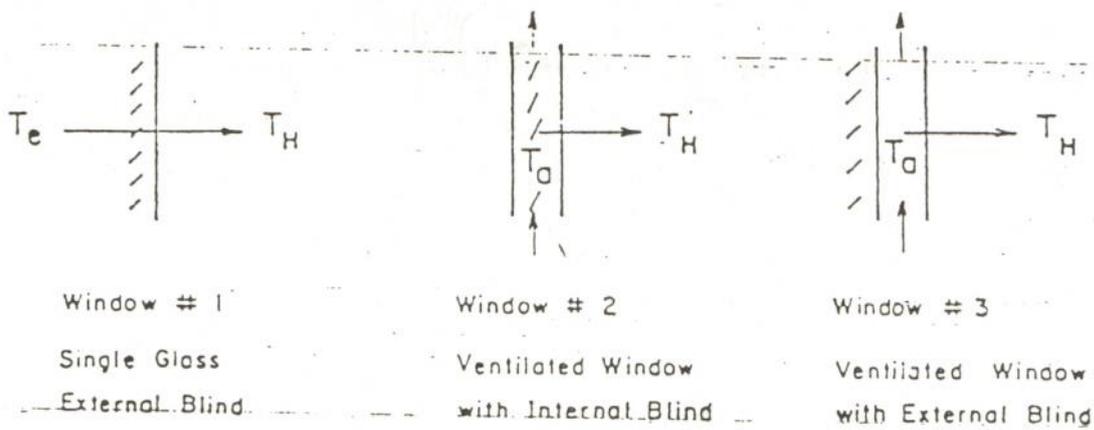


Fig. 3 Comparison of the Heat Gains through Three Types of Windows

Temperature, solar radiation, humidity and black globe temperature are installed within the test-house. Figure 2 illustrates all the sensors distribution positions.

5. THEORETICAL PRINCIPLE FOR THE VENTILATED WINDOW

The heat gain of the windows, not including the solar flux transmitted are:

= air conductivity

hr_1 , hr_2 and hr_3 can be calculated from the equation (9)

β = Thermal expansion coefficient,
 $1/(273 + T \text{ C})$

$$hr_{12} = E_{12} F_{12} (T_1 + T_2) (T_1^2 + T_2^2) \quad \dots(9)$$

ϵ_{12} = emissivity factor,
 = Stefan Boltzmann constant,
 $5.67 \times 10^{-8} \text{ W/m}^2\text{k}^4$

ϵ_1, ϵ_2 = emissivity surface 1,2
 F_{12} = factor depending on the surface 1 & 2 ratio

T_1, T_2 = surface temperature 1,2

hr_{12} = radiation coefficient depending on the T^3 . therefore it is quite stable

q_1, q_2 and q_3 can be calculated and compared to obtain the percentage of daily heat gain of:

$$PL2-1 = \frac{\int_0^{24hr} q_2(t) dt}{\int_0^{24hr} q_1(t) dt} \quad \dots\dots(10)$$

$$PL3-1 = \frac{\int_0^{24hr} q_3(t) dt}{\int_0^{24hr} q_1(t) dt} \quad \dots\dots(11)$$

$$PL3-2 = \frac{\int_0^{24hr} q_3(t) dt}{\int_0^{24hr} q_2(t) dt} \quad \dots\dots(12)$$

6. RESULT AND DISCUSSION

6.1 VENTILATED WINDOWS WITH INTERNAL AND EXTERNAL BLINDS

A ventilated window with horizontal internal blind is compared with a ventilated window with horizontal external blind and

a single glass window.

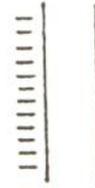
The recorded data calculated from equations (2) and (3) are plotted in figure 4 and 5. These values including convection and radiation but not the solar flux are presented in Table 1.



Window # 1
Single Glass
External Blind



Window # 2
Ventilated Window
with Internal Blind



Window # 3
Ventilated Window
with External Blind

Table 1. Comparison of Heat Gain Through A Ventilated Window with Internal and External Blinds and a Single Glass Window, for Convective and Radiative Gains (Daily Average Values for One Week).

(Air Flow Rate: 34.30 m³/hr/m Window Width)

(Window # 1) Wh/m ² /day	(Window # 2) Wh/m ² /day	(Window # 3) Wh/m ² /day	Ratio of the Heat Gain		
			$\frac{Wd \# 2}{Wd \# 1}$	$\frac{Wd \# 2}{Wd \# 1}$	$\frac{Wd \# 3}{Wd \# 2}$
1387	622	354	0.45	0.26	0.57

Discussion:

1. The heat gain through the window with an external blind is much lower than for the window with an internal blind (57%), because heat absorbed by the external blind is kept outside the room and the air gap.

2. The average daily energy savings for both windows, comparing to a single glass window, are 55% and 74% for window #2 and window #3 respectively

6.2 VENTILATED WINDOWS WITH DIFFERENT BLINDS POSITIONS

Two ventilated windows with internal blinds at different positions are compared. One window has the blind vertically closed and the other one has the blind horizontal. Both windows are compared with a single glass window and the results are shown in table 2 the recorded data calculated from equations (2) and (3) are plotted in figures 6 and 7.



Window # 1
Single Glass
External Blind



Window # 2
Ventilated Window
with Vertical Blind



Window # 3
Ventilated Window
with Horizontal Blind

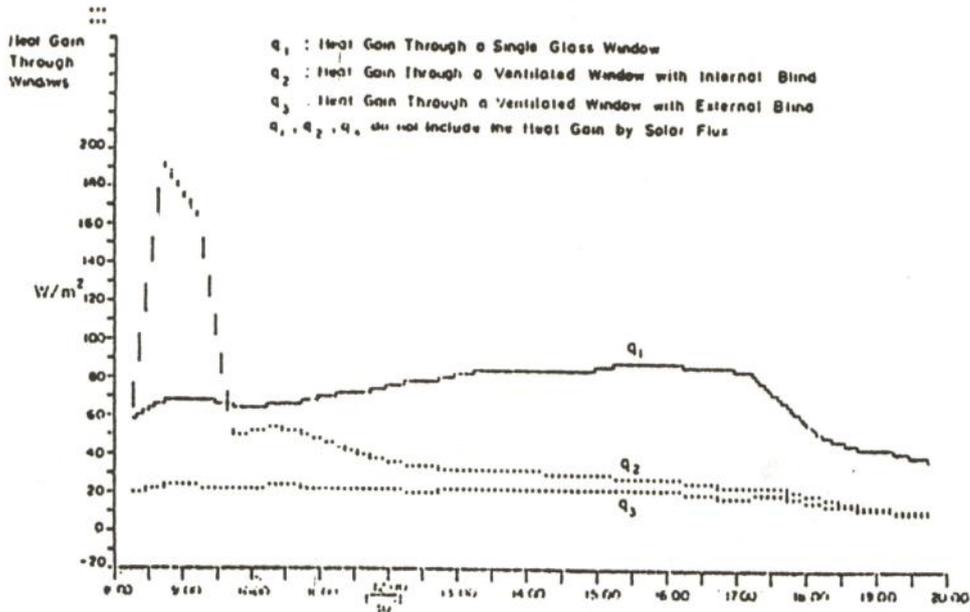


Fig. 4 Comparison of Heat Gain among Three Types of Windows on 03/06/83 Day Time (Air Flow:34.30 m³hr/m Window Width)

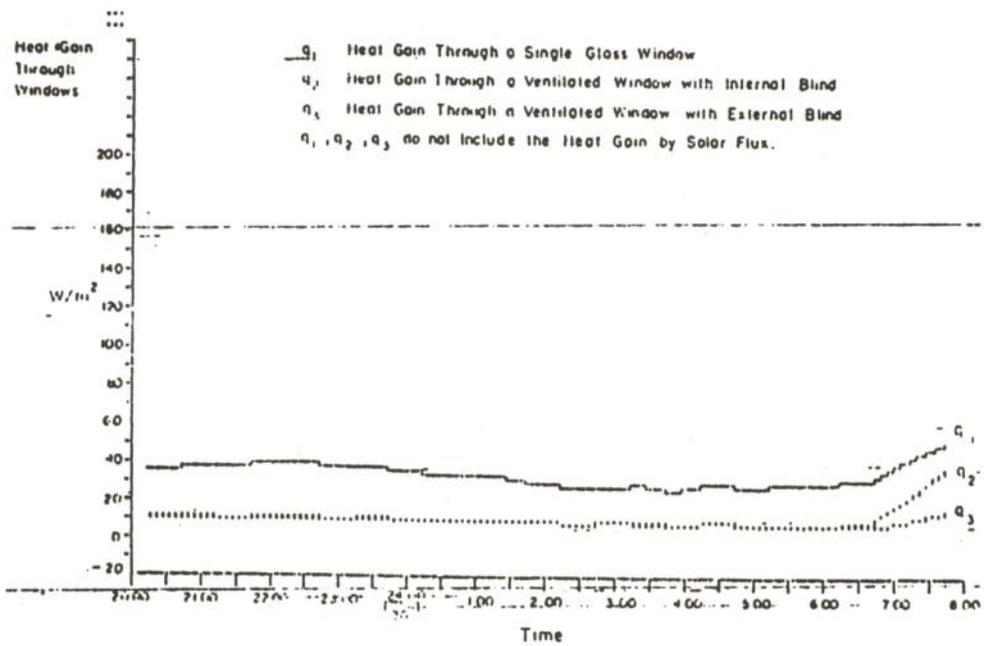


Fig. 5 Comparison Heat Gain among Three Types of Windows on 03/06/83 Night Time (Air Flow:34.30 m³/hr/m Window Width)

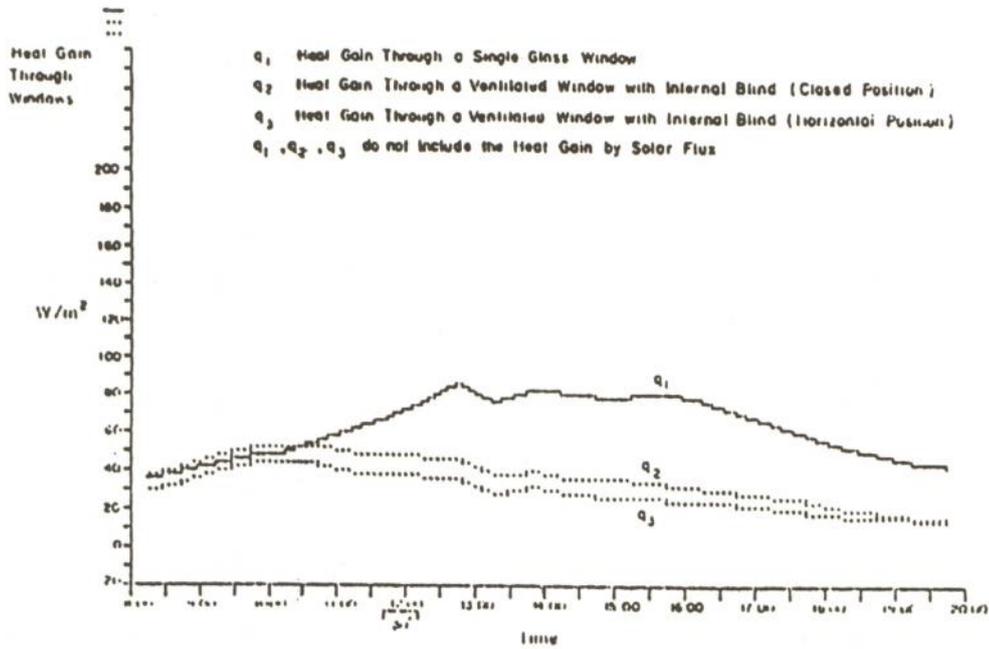


Fig. 6 Comparison of Heat Gain among Three Types of Windows on 30/04/83 Day Time (Air Flow. 34.49 m³/hr/m Window Width)

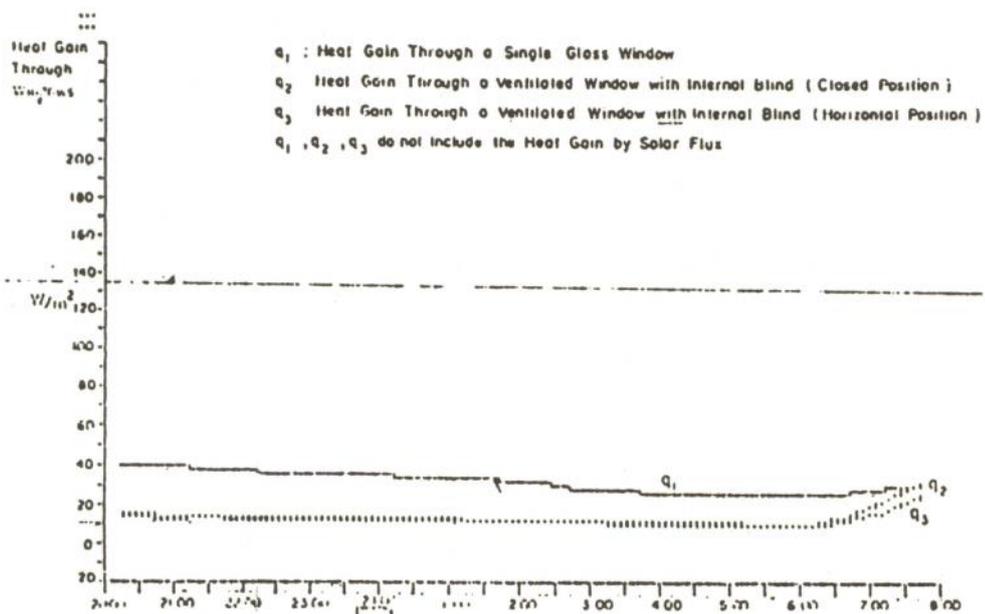


Fig. 7 Comparison of Heat Gain among Three Types of Windows on 30/04/83 Night Time (Air Flow 34.49 m³/hr/m Window Width)

Table 2. Comparison of Heat Gain Through a Ventilated Window With Internal Blinds at Different Positions, and a Single

Glass for Convective and Radiative Gain (Daily Average Values for One Week).

(Air Flow Rate: 34.49 m³/hr/m Window Width)

(Window #1) Wh/m ² /day	(Window #2) Wh/m ² /day	(Window #3) Wh/m ² /day	Ratio of the Heat Gain		
			Wd #2	Wd #3	Wd #3
			Wd #2	Wd #1	Wd #2
1050	555	455	0.53	0.43	0.82

Discussion:

1. The convective and radiative heat gain through the closed blind window is higher than through the horizontal blind window, (Table 2.). This is because the closed blind protects the sunlight from penetrating into the room but at the same time, absorbs more heat and rises the air flow temperature. The result shows the difference of heat gain of 18% between these two windows.

2. For both windows, the energy savings compared to a single glass window are significant. They are 47% for window #2 and 57% for window #3 for convective

and radiative heat gain.

3. When the window orientation is on the east position, people actually close the blind in the early morning till 8.30 a.m. and then rotate the blind to a horizontal position later. The heat gains through such kind of this window (window #4) comparing to a single glass window are presented in Table 3.

4. For this kind of ventilated window (Table 3). the energy savings compared to a single glass is 55% for convective and radiative and 45% when solar flux is included.

Table 3. Comparison of Heat Gain Through a Ventilated Window Having the Blind closed in the Morning and the Blind

Horizontal after 8.30 a.m., and a Single Glass Window. (Daily Average Values for One Week).

(Air Flow Rate: 34.49 m³/hr/m Window Width)

	(Window #1) Wh/m ² /day	(Window #4) Wh/m ² /day	Ratio of Heat Gain
			Window #4 Window #1
Convective and Radiative	1050	470	0.45
Solar Flux	393	320	0.81
Total Heat Gain	1443	790	0.55

7. ECONOMIC STUDY OF THE VENTILATED WINDOW

In this study, the six-storey office building of Chao Phra Ya Finance Limited, Nakornsawan, Thailand, is undertaken for economic analysis. The site of the building faces south with large glazed areas on the north and the south. The building is redesigned only in north and the south. The building is redesigned only in minor ways into what is termed a sun-tempering concept. The design uses exhaust air window on the north and the south facades. Ceiling air conduits with

exhausts are incorporated in the structure.

The ventilated windows are applied to second floor upto the sixth floor. The side doors leading to the side staircase are opened and closed by automatic systems to prevent unnecessary thermal gain.

This study is based on the analysis of the increasing capital cost of more glazings, additional venetian blinds, air conduits with exhaust electric fans and running cost and the saving corresponding to electricity saving during the life of the building.

Table 4. Additional Cost for Different type of windows

Cost (baht)	Single Glass Window Tinted	Double Glass Window Tinted	Ventilated Window Tinted	Double Glass Window With External Blind	Ventilated Window With External Blind
Window & frame	425,056	615,471	710,302	536,186	597,979
Venetian blind	—	—	—	117,000	117,000
Total cost	425,056	615,471	710,302	653,186	714,979
Additional cost compared to single glass window	—	190,415	285,246	228,130	289,923

Table 5. Comparison of Electrical Saving for Different Type of Windows.

Cost (baht)	Single Glass Window Tinted	Double Glass Window Tinted	Ventilated Window Tinted	Double Glass Window With External Blind	Ventilated Window With External Blind
Electrical consumption kWh/yr	124,909	107,145	86,463	92,095	79,196
Cost of electricity (baht) (1.54 B/kWh)	192,361	165,003	113,153	141,826	121,962
Energy Saving (B)	—	27,358	59,207	50,535	70,399

Table 6. Pay Back Period for Different Type of Windows

Years	Double Glass Window Tinted	Ventilated Window Tinted	Double Glass Window With External Blind	Ventilated Window With External Blind
	12.5	8.5	6.5	5.5

Assumption for Economic Analysis

- Deposit interest rate of 10% and present worth of a uniform series of amounts are used for the calculation
- No escalation rate of electricity cost is considered
- The capital investments are available for the projects

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The study of a special window designed for saving energy by reducing the air-conditioning load requirement has been analysed. The results of this analysis are presented as follows:-

- The ventilated window with an internal blind could reduce the thermal gain of about 55% compared to a single glass window with blind
- The ventilated window with an external blind gave even a much better thermal gain reduction of 74%
- The energy saving was 47% for an internal blind closed position and 57% for the horizontal blind position

In this study, the ventilated window is experimented in the south and east facades. It was found that the internal blind in-between glazing can be effective in the south facade where there is not too much direct flux throughout the year. But the situation is worse than a single glass when it is in the east facade if the air flow through the ventilated window is not large enough. It is better to

use an external blind, a porch or a shutter to shade the direct flux.

Another point of view is that, even though the external blind is very effective at reducing solar heat gain, it may be susceptible to weather damage. Internal blind has limited ability to reflect incoming solar radiation back out of the window. Rotating blind between the glazing can solve these problems. Surface temperature on the inside glass is actually the same as room air temperature. The blind is not susceptible to weather damage and require minimal maintenance. Dirt does not accumulate on glazing or blinds in air space between panes due to the constant forced upward air movement.

Another benefit of the ventilated window is the reduced sound transmission-minimizing external noise disturbance.

The installation of the double glazed window means more money for glazing. The corresponding sum of energy saving for air conditioning during the life of the building offer benefits to the user.

8.2 RECOMMENDATION FOR FURTHER STUDY

In view of what has been done so far, it is worthwhile to conduct the experiment of ventilated window under natural convection.

The other interesting topics to be considered are:

- effect of triple glazed window.
- tinted glass.
- downward exhaust air flow.
- ventilated walls.

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