香港城市大學
City University
of Hong Kong

DEPARTMENT OF BUILDING & CONSTRUCTION

建 築 學 系

Research Report

Title: An investigation of optical performance and energy implications of V-KOOL film coating using in air-conditioned cellular offices

Author(s): Dr. Danny H. W. Li, Dr. Joseph C. Lam, Mr. Chris C. S. Lau, Mr. T. W. Huan

Date: 23 September 2002

Acknowledgements

The authors would like to thank Ir Martin Wu of EEO (EMSD), Ms Poon and Ms Kwan of EPD, and Mr Terence Li and Mr Patrick Kam of V-KOOL for their help throughout duration of the project. The authors would also like to thank all the technical staff and student assistants for their help with the on-site measurements.

1. Introduction

In Hong Kong, air-conditioning and artificial lighting are the two major electricity consuming components in cooling-dominated office buildings. Solar heat gain, particularly via fenestration, constitutes a significant proportion of the total building cooling load. More solar radiation means more total solar heat gain and, hence, more cooling requirements and larger air-conditioning plant. In recent years, there has been an increasing interest in incorporating daylight to the architectural and building designs to save energy. Effective daylighting has a strong potential for reducing energy demand in non-domestic building by utilising daylight more effectively.

Companies begin to recognise that efficient use energy can reduce operating costs and also has important environmental benefits. Daylight is considered as the best source of light for good colour rendering and closely matches human visual response. It does make an interior space look more lively and attractive. The amount of daylight entering a building is mainly through window openings that provide the dual function not only of admitting light into the indoor environment, but also in connecting the inside of a building to the outside world. People expect good natural lighting in their working places. Daylight, however, is always accompanied by solar heat gain. The benefits from daylight may be penalised by the increased solar heat gain. Moreover, because of the small angle of incidence, direct sunlight can be excessive for east- and west-facing windows in early morning and late afternoon. To avoid the problems of glare, excessive brightness and thermal discomfort, occupants may block the windows all the time using internal shading devices, resulting in poor daylighting performance and very small electric lighting energy savings.

Recent advances in thin film coatings for window glass products provide a means of substantially reducing heat gain without proportionally reducing daylight transmittance. It means that the energy expenditures due to lighting and cooling requirements can be minimised while people can enjoy more natural light and maintain visual contact with the outside environment. A research project was initiated to evaluate the optical performance of a solar control film coating known as V-KOOL with the following objectives:

(a) To obtain detailed information on the solar heat gain and daylight availability for typical cellular offices in Hong Kong with and without the V-KOOL film on the window glass.

(b) To determine the optical performance of the V-KOOL solar control film in terms of solar heat and daylight illuminance rejection under various sky conditions.

(c) To compute the probable overall energy expenditures and cooling requirements when the V-KOOL films are being used in air-conditioned office buildings.

The work involves field measurements of the solar heat gain and daylight illuminance in two air-conditioned cellular offices. This report describes the measurements, presents the findings and discusses the design implications.

2. Building and Cellular Office Description

Southorn Centre is a fully air-conditioned office building located at 130 Hennessy Road, Wanchai, Hong Kong (see Photo 1). It is a 31-storey (17/F is a mechanical floor) commercial building of which 26 storeys are mainly office spaces and a centralised heating, ventilating and air-conditioning (HVAC) system is used. The internal dimensions are of about 43m x 32m and the floor-to-floor height is 3.5m with a window-to-wall ratio (WWR) of around 0.5. The main office areas are located at the north- (facing Hennessy Road), south- (facing Johnston Road) and west-zones (facing Southorn Playground). The measurement was carried out on the 28th Floor. The cellular offices are built along the west perimeter zone while open plan offices are designed mainly at the south perimeter zone. Staircases, meter rooms, service lifts, A/C plant rooms and toilets are located at the interior core and temporary owned and unowned spaces including lift lobbies, storerooms and conference rooms are placed in the east zone (facing a residential building). The part floor plan at 28th floor is shown in Figure 1.

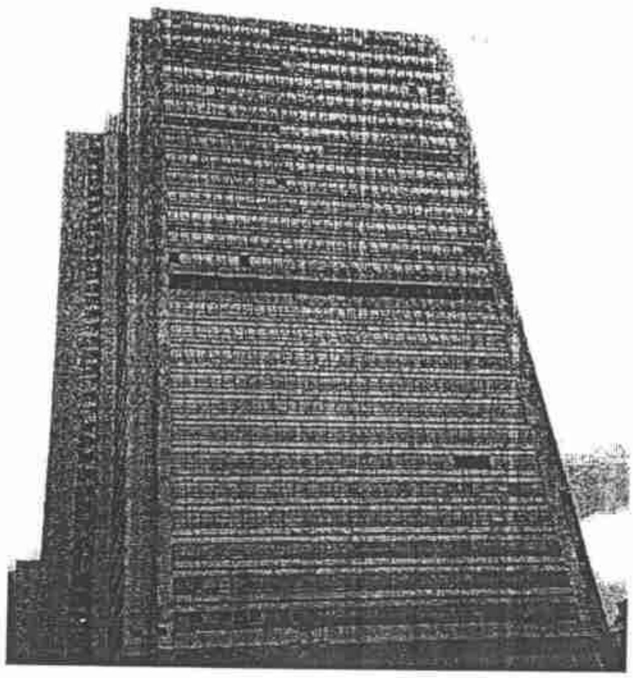

Photo 1 Southorn Centre

Fig.1 Part plan at the 28^{th} floor of Southorn Centre

Two cellular offices (Rooms 2803 and 2817) located on the 28th floor along the west perimeter zone were used for the study. The dimensions of Room 2817 are 3.6m (depth) x 2.4m (along the window) x 2.8m (floor to ceiling height) and the net window area is 3.55m². There are a total of 4 ceiling-mounted recessed fluorescent luminaires with standard diffusers. Each luminaire consists of three 18 W fluorescent tubes with dimmable electronic ballasts, which can dim lamp output smoothly and uniformly. The indoor illuminance levels due to electric lighting only (venetian blinds were used to block the daylight) was measured to be 530 lx. A light sensor was used to control the light output from the luminaires. The light sensor had two functions. First, it detected the level of lighting (including daylight) and automatically adjusted the artificial lighting level of the luminaires. Second, it served as an occupancy sensor to switch off the light fittings when the room was empty.

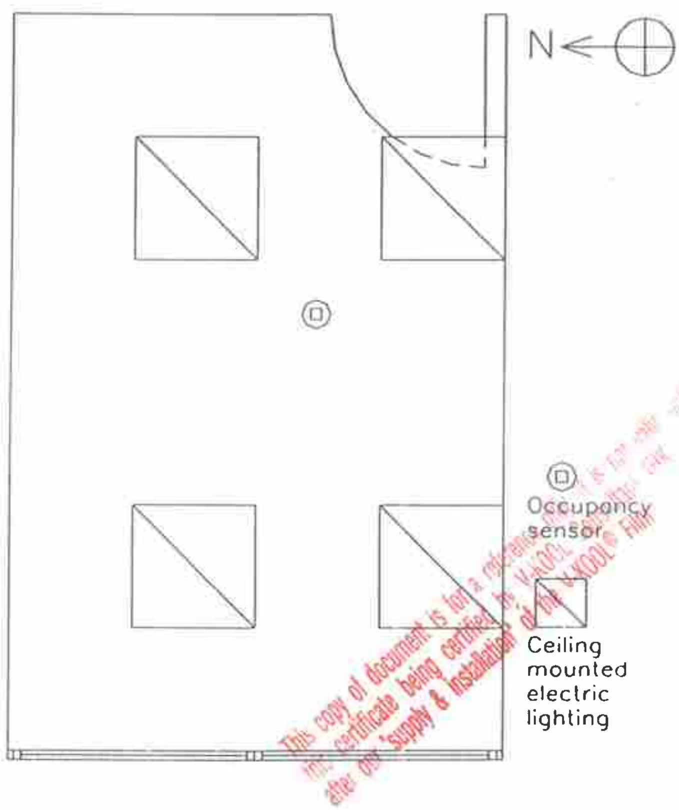

Fig.2 Electric lighting layout plan for Room 2817

Room 2803 is 3.5m (width) x 4.8m (depth). Same artificial lighting system as Room 2817 is used. Totally, six ceiling-mounted luminaires plus one wall mounted luminaire of 36 W were installed. With a bigger floor area and more luminaires, two sensors are used to monitor the ceiling-mounted light fittings and the internal illuminance level was found to be 680 lux. Figures 2 and 3 present the electric lighting layout plan with the dimming systems for the Rooms 2817 and 2803, respectively.

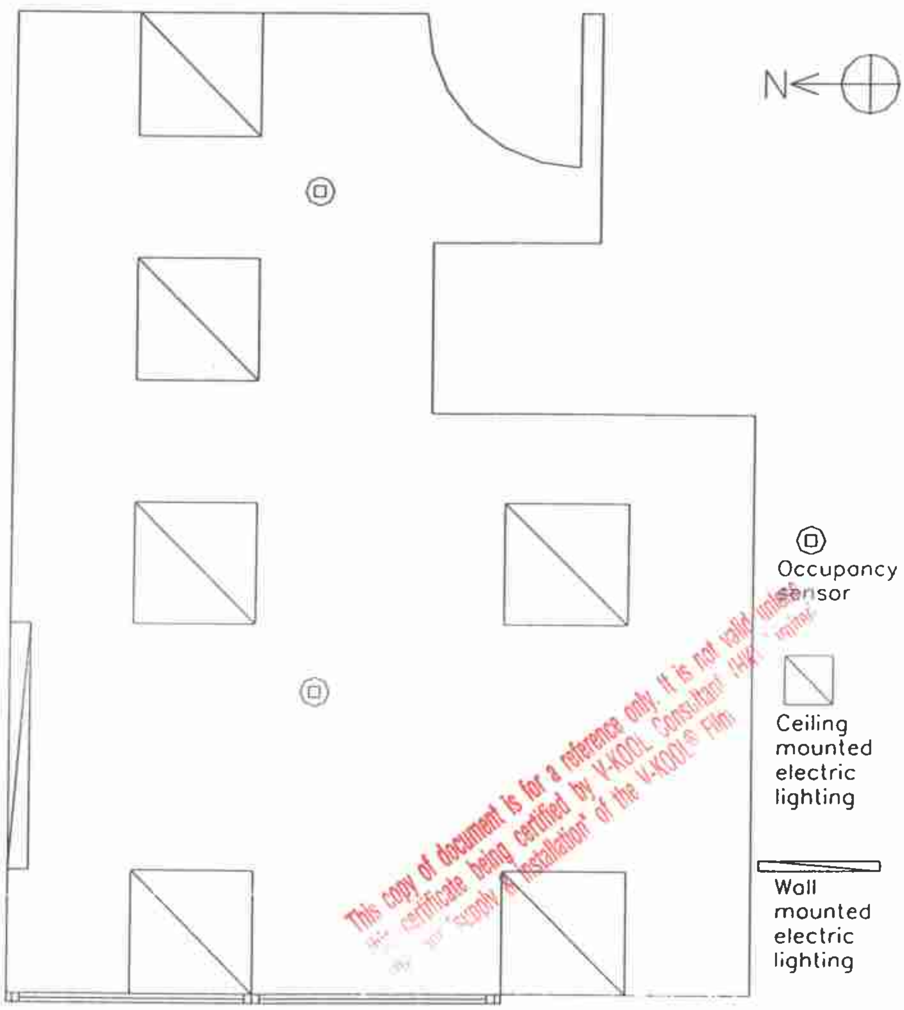

Fig.3 Electric lighting layout plan for Room 2803

3. Measuring Equipment

The measurements of interior solar heat gain, daylight availability and electricity consumption were made by means of pyranometers, illuminance meters and a power analyser, respectively. The solar heat and daylight illuminance data measurements started from sunrise and finished after sunset and the electric lighting energy measurement was based on the typical office hour in Hong Kong (08:00-18:00).

Two pyranometers (See photo 2) manufactured and calibrated by Kipp and Zonen, Netherlands, were used to record the solar radiation separately for Room 2803 (with V-KOOL films on the windows) and Room 2817 (without V-KOOL films on the windows). Since it is a fully air-conditioned office building, only transmitted solar radiation data were logged. The two pyranometers were connected to an integrator, which calculated the radiation at an interval of 10 minutes. The data from the integrator were sent to a notebook computer for storage through a RS232C cable.

Photo 2 A pyranometer used for interior solar heat measurement

Similarly, the transmitted daylight illuminance data via window glass with and without V-KOOL film coatings were recorded by two illuminance meters produced by Minolta of Japan (See photo 3). The silicon photocells with cosine and colour corrections, measure illuminance level up to 300klux with an accuracy of 2%. A multiple illuminance measurement system was adopted and the two receptor heads were connected serially with extension cables, which transmitted all the measured data to the main body adapter. A data-management software namely, T-A30, was used to capture the measured results simultaneously twice per second, averaged over a minute in order to simulate the dynamic variations. The logged data were sent to another notebook computer for storage.

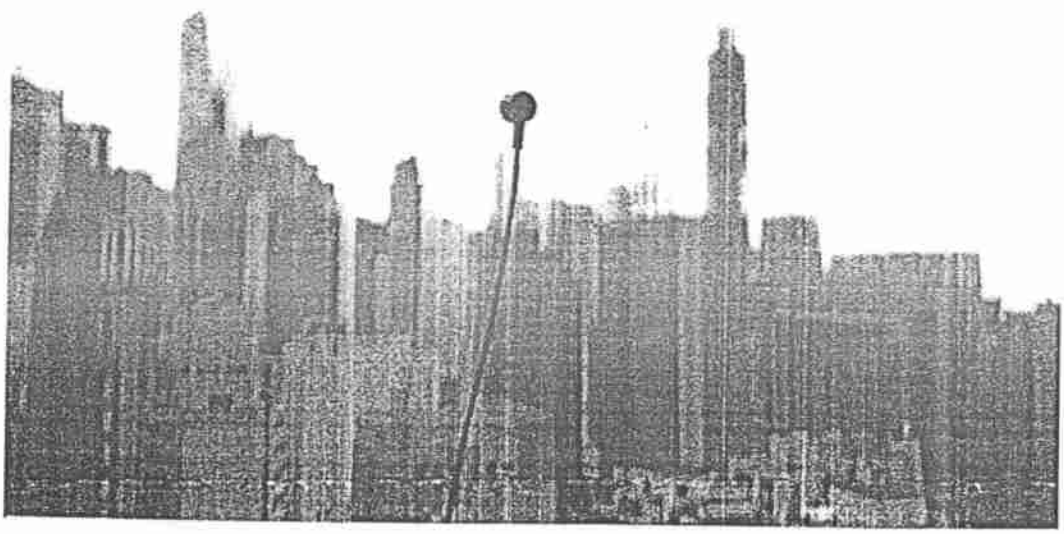

Photo 3 An illuminance sensor used for daylight illuminance measurement

A power analyser (See photo 4) and its accessories including AC current probe, test leads, test probes and test clips manufactured by Fluke, Netherlands were used to perform the measurement of electric lighting consumption. A software called FlukeView 43 Windows was used to capture the data measured from the analyser and transmit these data to another notebook computer. Again, the data were averaged over 1-minute interval to match the measured daylight illuminance results.

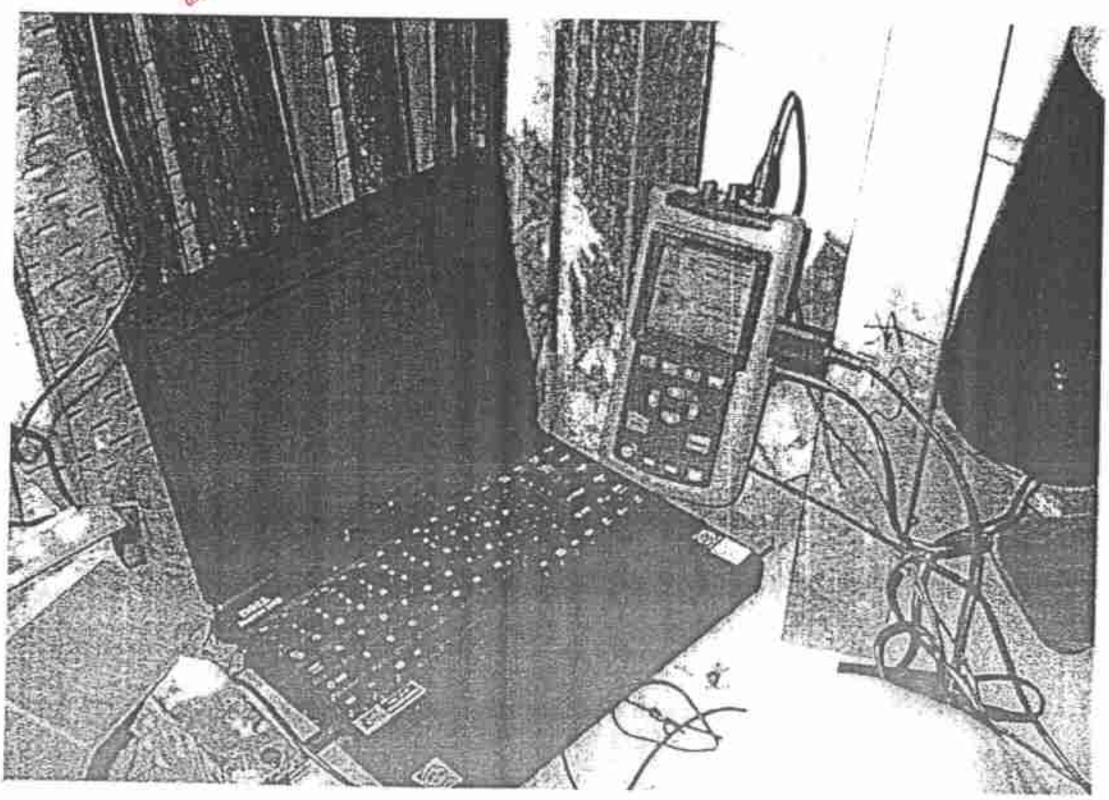

Photo 4 A power analyser used for electric lighting energy consumption measurement

4. Data Analysis

Measured parameters include interior solar heat gain and daylight illuminance, and electric lighting consumption. Field measurement was conducted between late June and early August 2002. Due to site restriction, the pyranometers could not be fixed vertically to measure the solar radiation. Instead, we measured the solar radiation on a horizontal surface for two cellular offices with and without using V-KOOL solar control film to obtain the solar radiant heat transmittance for the V-KOOL film. Based on the luminous efficacy model developed for Hong Kong, vertical solar radiation components falling on window surface of the cellular offices were computed. Applying the measured solar radiant heat transmittances for the window and the V-KOOL film coating, solar heat gain for the two cellular offices with and without using V-KOOL film coating was determined. Since solar radiation and daylight illuminance data were recorded by separate equipment and notebook computers, instrumentation malfunction occurred at different time during the measuring period. In all, 20 sets of daily readings for solar radiation and daylight illuminance were made available. The measured results and findings are presented as follows:

4.1 Solar heat gain

Solar heat gain through fenestration is considered as the largest contributor to building envelope cooling load in the tropic and sub-tropical regions. Effective solar heat control means not only reduction in cooling energy and smaller HVAC plant size, but also minimising the overheating problems and contributing to thermal comfort. The daily, hourly and frequency distribution of the measured solar heat data were computed and analysed.

4.1.1. Daily performance

Graphical representation is a simple and direct approach to analyse and interpret the measured data. The features can reflect the daily performance of the solar control films in terms of solar heat reduction. Figure 4 shows the measured solar radiation data for the two cellular offices with and without using V-KOOL film coating on the window glass. It can be seen that the daily measured solar heat varies from one day to another but similar patterns can be observed for the two curves indicating that the same amount of solar radiation falling on the facades of the two rooms. The V-KOOL window coatings do reduce solar radiation entering into the room space in particular when large amount of solar heat is recorded. When the V-KOOL film coating is being used, the peak daily solar heat gain of 2360 Wh/m² is lowered to less than 1300 Wh/m², representing a 45% drop. Similar solar heat reduction ratio is obtained for the solar radiation values of 1600 Wh/m² or more. As the solar radiation decreases, the solar heat rejection ability of the film coating becomes smaller. For instance, the V-KOOL film coating can only cut the daily solar heat from 560 to 430 Wh/m², representing around 25% reduction. Large solar radiation usually represents a sunny sky with a large portion of direct component of high values. Low solar heat indicates a cloudy sky, which is dominated by diffuse solar component. It means that the solar heat reduction ability of the V-KOOL film coating is directly proportional to the amount of solar radiation received. Since the two offices face the west, pure diffuse solar heat of low levels and direct components of high solar heat values would be received in the morning and in the afternoon, respectively. The performance of the V-KOOL film coating in a sunny afternoon would be much better than those recorded during other measurement periods.

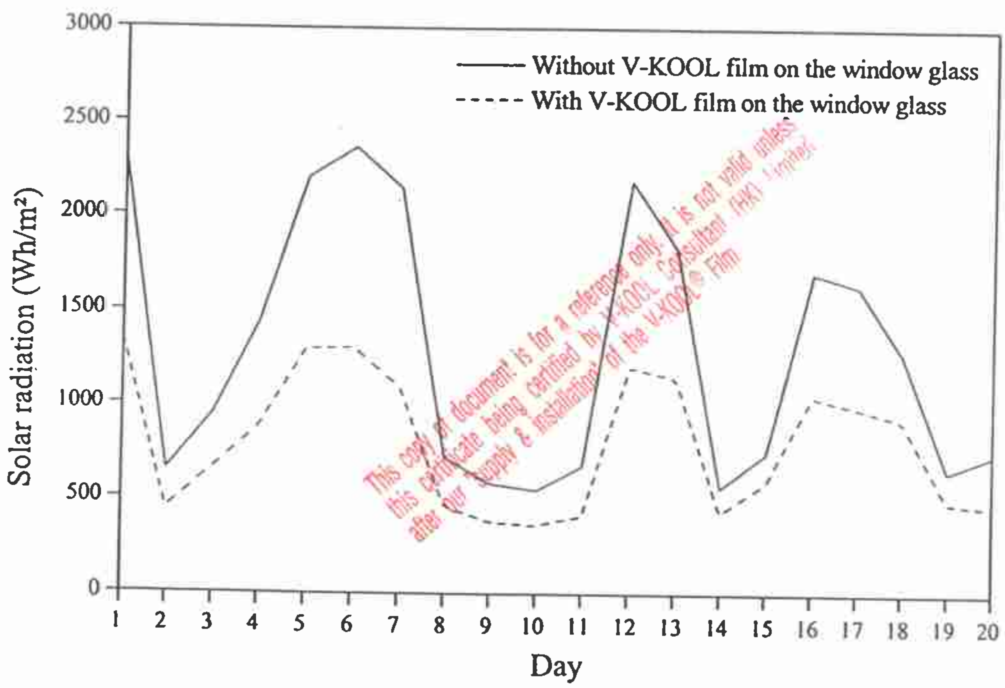

Fig. 4 Daily interior solar heat for the two rooms

4.1.2. Hourly performance

To further examine the characteristics of the V-KOOL solar control film, two daily solar heat data recorded on 12th July and 29th July representing for maximum and minimum measured solar radiation were selected. Figures 5 shows the hourly solar heat between 8:00 and 18:00 measured on 12th July (maximum daily solar heat received). It can be seen that the measured solar heat data for the two rooms have very similar trends and peak at the same time (i.e. 16:00). As expected, the maximum solar heat reduction appears at the peak solar heat value. In the morning when the solar radiation data are mainly diffuse of low values, the solar heat transmittance becomes smaller. The solar heat reduction ranges from 11% at 8:00 to 56% at 16:00. The finding supports that the solar heat transmittance of the V-KOOL solar control film depends strongly on the amount of solar heat received.

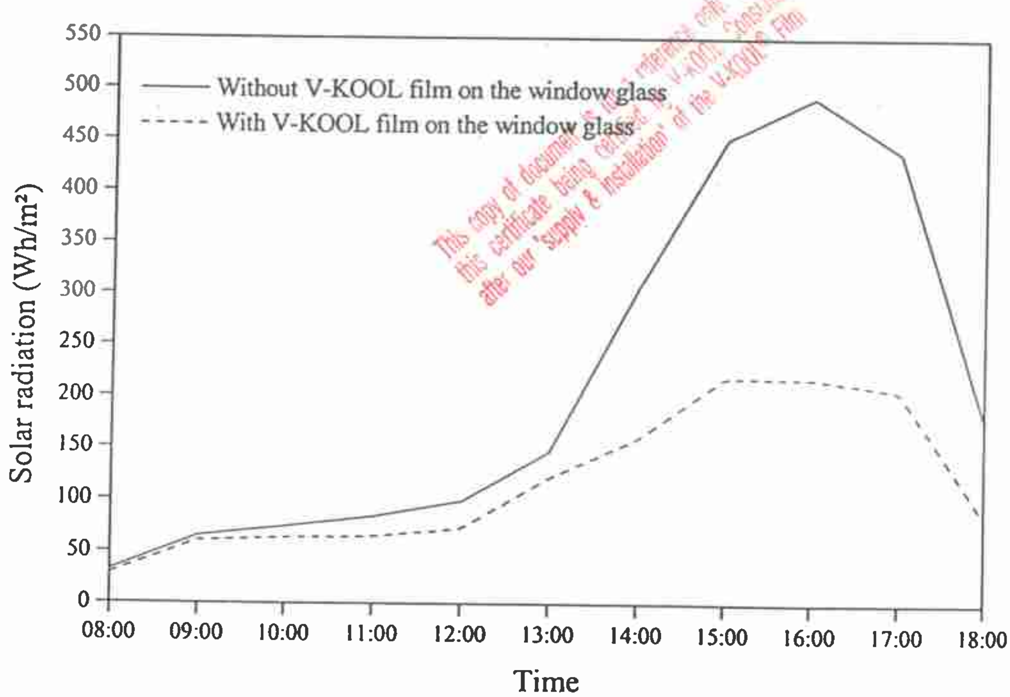

Fig. 5 Measured daily interior solar heat profiles on 12th July 2002

Likewise, the daily solar heat profile for 29th July (minimum daily solar heat received) was computed and is shown in Fig.6. The pattern is rather different from that in Fig.5. The peak value is found in the morning instead of in the afternoon and very small amounts of solar heat appear between 13:00 and 18:00 indicating bad weather conditions occurring in the afternoon. This graph highlights the performance of the V-KOOL film coating when the solar radiation is purely diffuse component. In general, solar heat is gently reduced from 130 to 86 W/m^2 at 11:00 and slightly decreased in the afternoon. It is surprising to note that there is almost no reduction when the hourly solar heat is less than 20W/m^2.

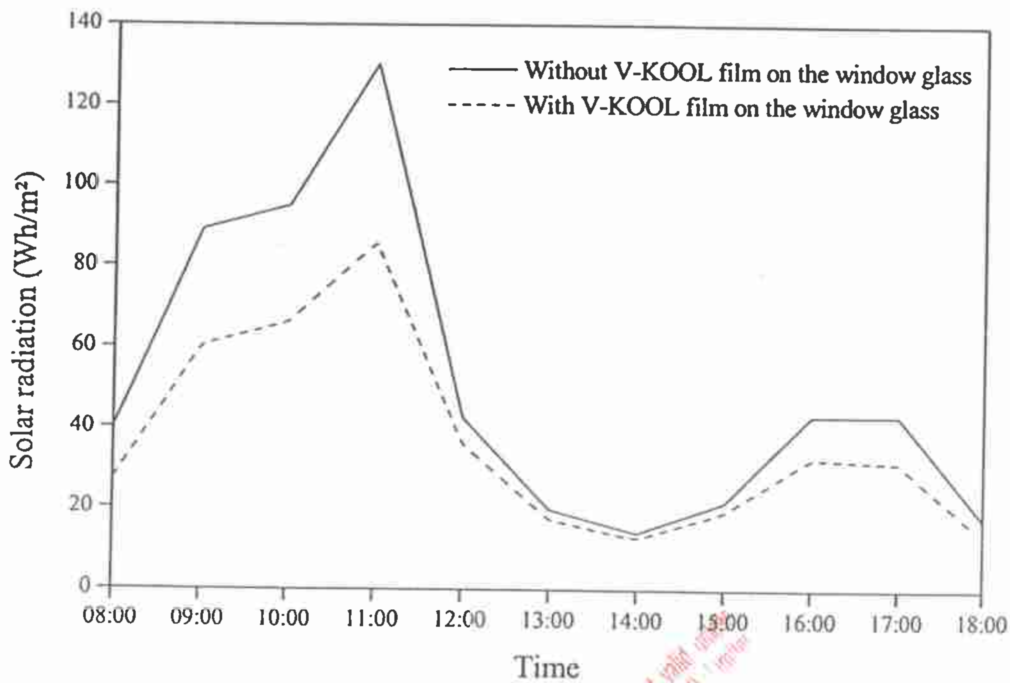

Fig. 6 Measured daily interior solar heat profiles on 29th July 2002

4.1.3 Average daily profile and energy savings

To study the average performance of the film coating, mean daily solar heat profile based on the 20 sets of daily data was determined and is plotted in Fig.7. Significant solar heat reductions are observed between 14:00 and 17:00 showing that bad weather conditions were not common in the afternoon during the measurement period. In general, the features are quite similar to those in Fig.5. The areas under the two curves in Fig. 7 indicate the average daily amount of solar heat received by the two rooms and hence the solar heat rejected by the V-KOOL film coating. Taking typical office hours of 8:00-18:00 in Hong Kong, the amount of daily solar heat reduced was obtained. In order to provide an indication of the likely solar heat reductions for a month and the whole year, the monthly and annually values were extrapolated from the data collected during the measurement period. The results are summarised in Table 1. The effect of using V-KOOL film coating was a reduction of solar heat of around 15 kWh/m² per month and 183 kWh/m² per year for cellular office facing west. **The calculated solar heat reductions were quite substantial.**

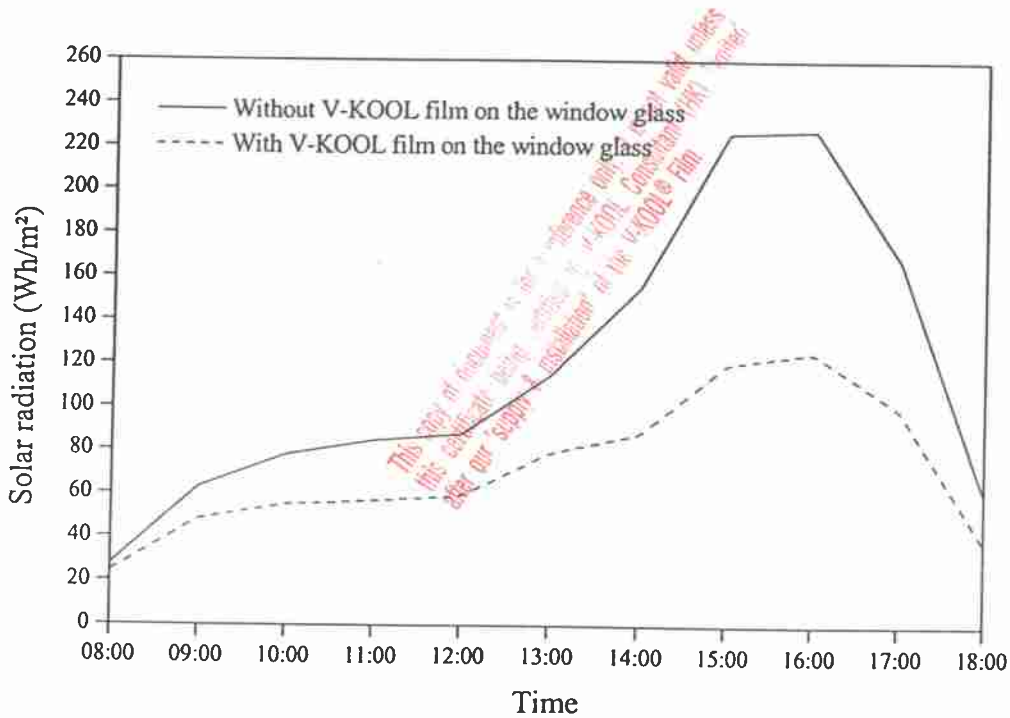

Fig. 7 Average daily interior solar heat profiles

Table 1 Solar heat energy per unit window area

	Without V-KOOL film coating on the windows	With V-KOOL film coating on the windows	Reduction
Daily	1.29kWh/m²	0.79kWh/m²	0.5kWh/m²
Monthly (30 days)	38.7kWh/m²	23.7kWh/m²	15kWh/m²
Annually (365days)	471kWh/m²	288kWh/m²	183kWh/m²

4.1.4. Peak solar heat

The usual practice for the design of HVAC systems involves computation of peak design load at a specific hour of a design day based on the required indoor and prevailing outdoor design conditions. The weather data representing severe climatic conditions are employed in the design load calculations for determining peak design loads and the appropriate capacity of HVAC plants. For a building with large window areas and steady occupancy throughout the day (e.g. high-rise commercial buildings), the peak cooling load would be the time corresponding to the maximum solar heat gain. In Hong Kong, peak cooling load for commercial buildings occurs in summer afternoon. Apart from decreasing the cooling energy, proper use of solar control film would also reduce the peak cooling load and hence plant capacity. There is no uniform basis for defining the system reliability of individual design weather variables such as solar radiation. The design load is the load, which will only be exceeded for reasonably small percentages of time, such as 1, 2.5 or 5% of a certain period indicated by the cumulative frequency of occurrence. The cumulative frequency distribution of solar heat showing the percentage of the working period in which a given solar heat is exceeded is useful for determining the probable reduction of peak cooling load due to the solar control film.

Figure 8 presents the cumulative frequency distributions with an interval of 1W/m² for the solar heat gain for the two cellular offices based on the normal office hour 8:00-18:00. The effects due to the V-KOOL film coating can be observed. For solar heat levels less than 80W/m², the film coating effects are not so significant, since low solar heat levels often mean that the solar component is mainly diffuse and the solar heat reduction would only be about 30%. For large solar heat values, which are often accompanied by direct sunlight, the differences are significant. It can be seen that a peak solar heat value of 640W/m² drops to less than 365 W/m² when the V-KOOL film coating is used. As peak cooling load would be the time corresponding to maximum heat gain through the building envelope, limiting the solar heat gain could effectively lower cooling load and potential for smaller HVAC plants.

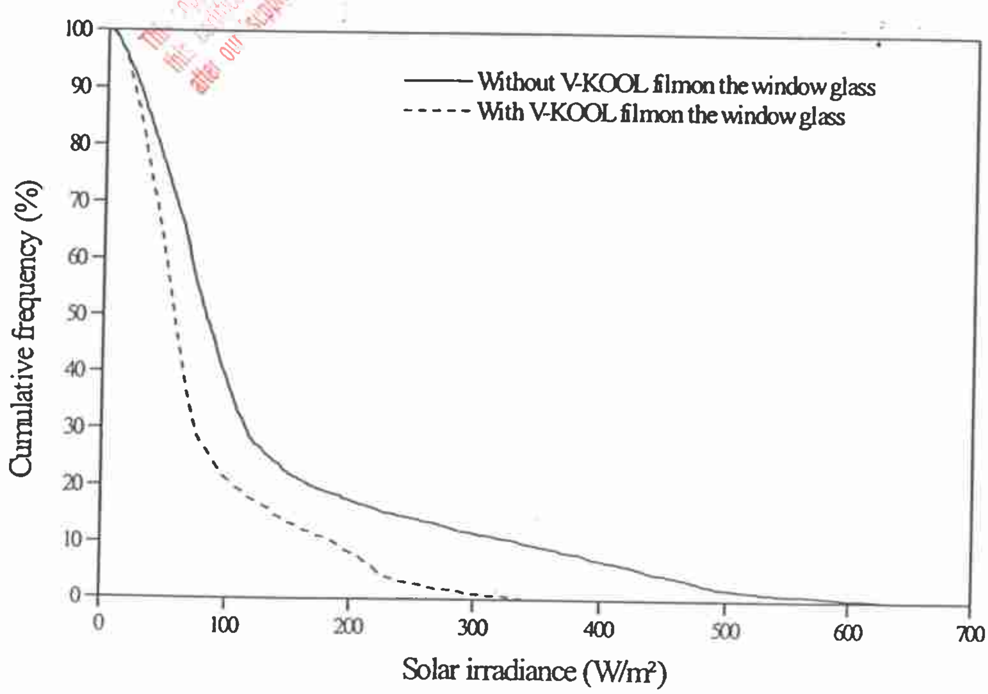

Fig 8 Cumulative frequency distributions for solar heat via windows with and without the use of V-KOOL film coatings

4.2. Daylight Illuminance

As indicated in Photo 3, the measured daylight illuminance data were the product of the overall light transmittance of the fenestration system (with and without the solar control films) and the vertical illuminance on the window. Based on the measured transmitted daylight illuminance data with and without V-KOOL solar control film on the windows, the average values were calculated and are presented in Fig.9. The averaging was carried out over a 10-hour day between 08:00 and 18:00, corresponding to the normal office hours. Similar trends can be observed between the two curves. Both curves show the peak daylight illuminance on the same day. The V-KOOL film coating can reduce larger amount of daylight illuminance when the outdoor illuminance admitting through the glazing is high and vice versa. However, a closer examination of the two curves revealed that the visible light transmittance is quite constant for all measured data. The visible light transmittance for the V-KOOL film coating was found ranging from 76.1 to 77.5% with an average of 76.7%. The standard deviation was about 0.3%, representing only 0.4% of the mean value. Unlike solar radiation, the visible light transmittance of V-KOOL film coating appeared to be constant and did not depend on the amount of daylight illuminance falling on the window surface.

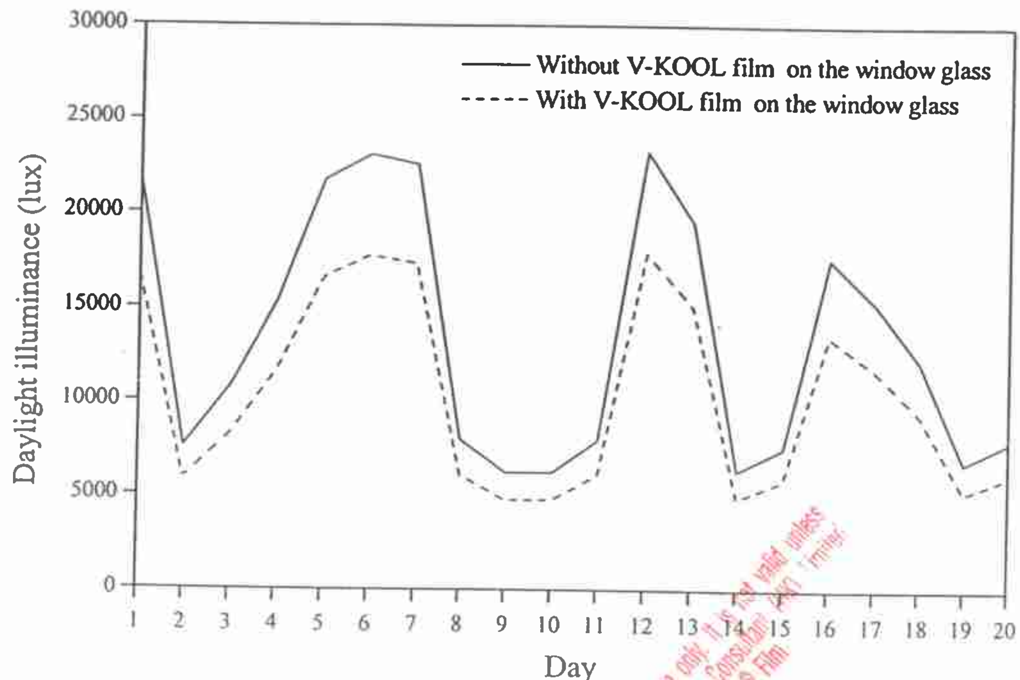

Fig. 9 Average hourly daylight illuminance for the two rooms

To further investigate the light transmittance of the V-KOOL film coating for a particular day, the daily daylight illuminance profile on 12th July (i.e. peak daily solar heat gain) is plotted in Fig.10. Using the V-KOOL film coating, the peak daylight illuminance of 49 klux at 16:00 reduces to around 37 klux. In terms of percentage, both the highest and lowest values appear in the afternoon, ranging from 75.8% at 14:00 to 78.1% at 18:00. It shows that the light transmittance of V-KOOL film coating does not depend on whether the daylight illuminance consists of direct component.

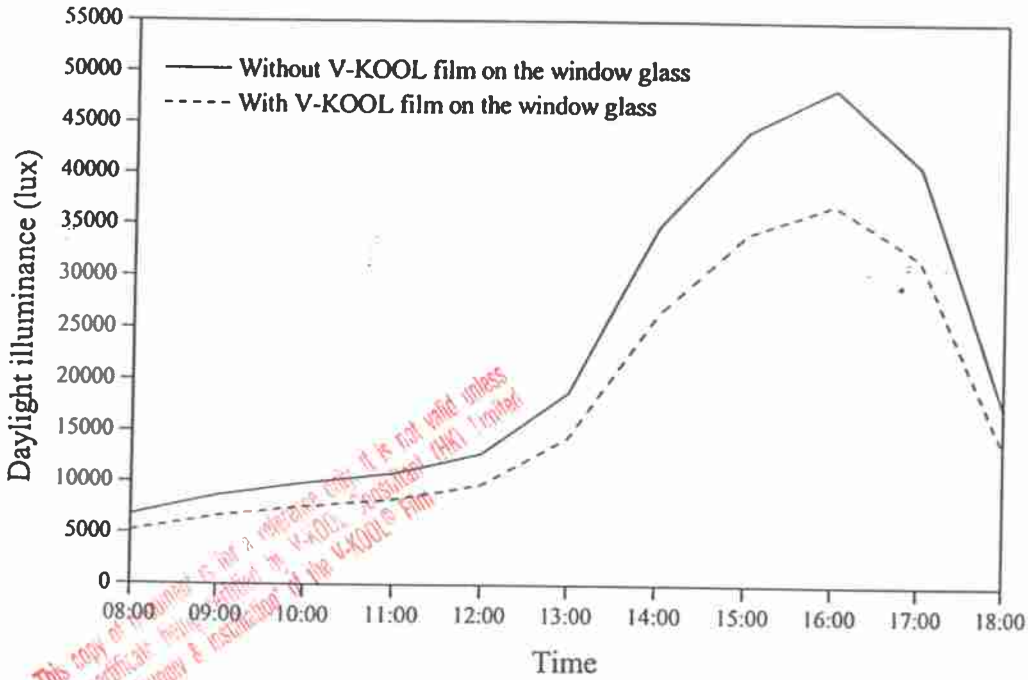

Fig.10 Measured daily daylight illuminance profiles on 12th July 2002

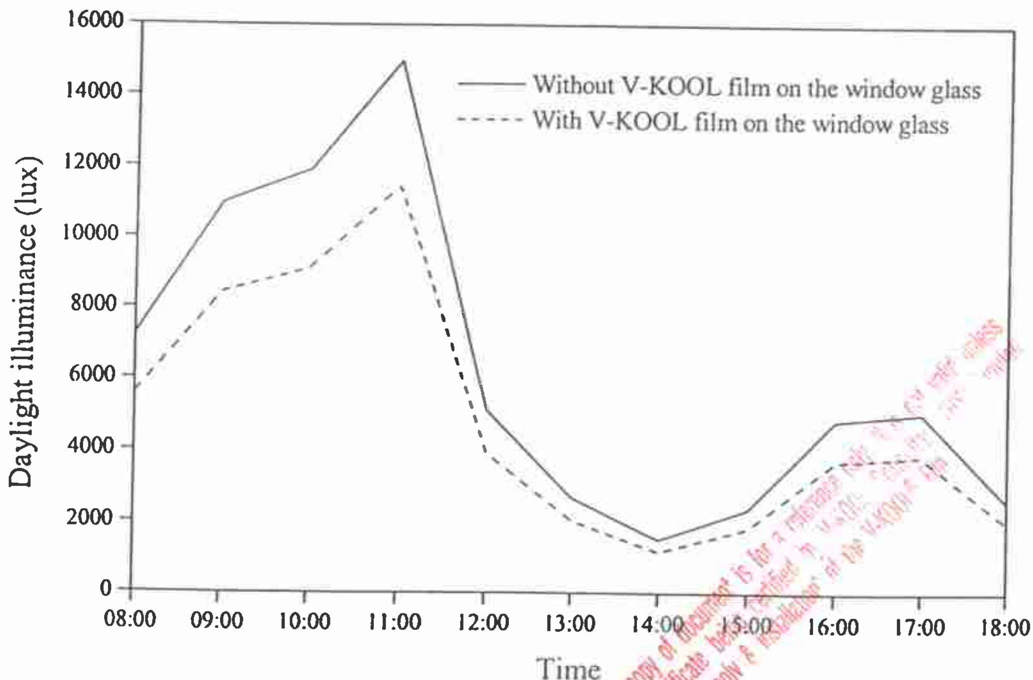

Fig.11 Measured daily daylight illuminance profiles on 29th July 2002

Similarly, the daily daylight illuminance profile on 29th July (i.e. minimum measured solar heat) was computed and is shown in Fig.11. The trends of the two curves match closely with the corresponding lines shown in Fig.6 where the measured data were 'diffuse-oriented'. The average light transmittance was 76% with variation less than 1.2%.

4.3 Correlation between daylight illuminance and electric energy savings

High daylight availability contributes more daylighting savings. Fenestration system with large area and high light transmittance appears to be very suitable for daylighting schemes. Since the cellular offices face the west, diffuse-oriented of low illuminance levels would be obtained in the morning but high proportion of direct sunlight may be received in the afternoon. The occupants may pull the blinds up in the morning to admit more diffuse daylight. In the afternoon, blinds are lowered down to block out direct solar glare. However, it has been pointed out in the literature that two reasons cause the reduction of energy savings from daylight linked systems using manually controlled shading devices. Firstly, blinds are used to provide more shading than is really necessary. Secondly, shading is not quickly reduced when the conditions change. For example, the occupants may not know the outside condition after the blinds are pulled all the way down. Considerable effort was made to obtain a continuous record of data reasonably indicating the electric lighting savings due to daylight. In all, two sets of 1-minute data measured in morning period (9:00-12:30) and afternoon period (13:30-18:00) were used for analysis. The lunch-time from 12:30 to 13:30 was excluded for the calculation because the occupancy sensor automatically switched off the light fittings when no body was inside the office. Figures 12 and 13 present the correlation between the measured daylight availability and the lighting energy savings for the morning period and afternoon period, respectively. It can be seen that data are rather scattered, but linear correlations with different slopes can clearly be identified for individual graphs. Through regression analysis, the following linear regression equations were obtained:

$$S = 3.5\,L - 8.2 \qquad (1)$$

(for the morning period, R^2=0.84)

$$S = 1.2\,L - 2.4 \qquad (2)$$

(for the afternoon period, R^2=0.95)

where S = the electric lighting energy savings (%)

L = daylight availability (klux)

Equations 1 and 2 show that there will be no electric lighting energy savings until the daylight illuminance reaching to 2.3 klux or more in morning period and 2 klux in afternoon period. With the coefficient of determination (R^2) over 0.84, the linear correlations for the two equations are considered strong, and it is argued that the electric lighting energy load is well correlated with the daylight availability. It supports that in a side-lit room, interior daylight may be more nearly proportional to the amount of daylight falling on the window. The savings shown in Equations 1 and 2 would be quite small with respect to the daylight illuminance received particularly for the afternoon period. The amount of natural light read by the sensors depends on the window size, light transmittance and the internal reflectances. The main reason may be due to the fact that a considerable window area was blocked by the venetian blinds especially when direct sunlight penetrated into the room. Nevertheless, Figs 12 and 13 provide a good indication of the actual electric lighting energy savings due to the present photoelectric lighting control system.

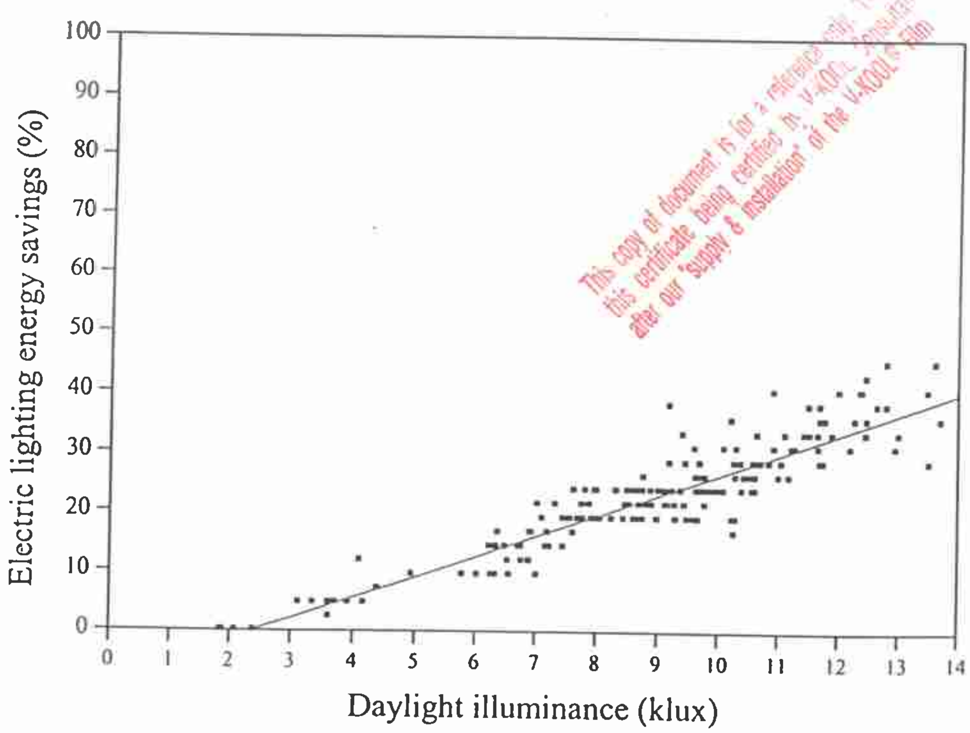

Fig.12 Correlation between daylight availability and artificial lighting energy savings for morning period

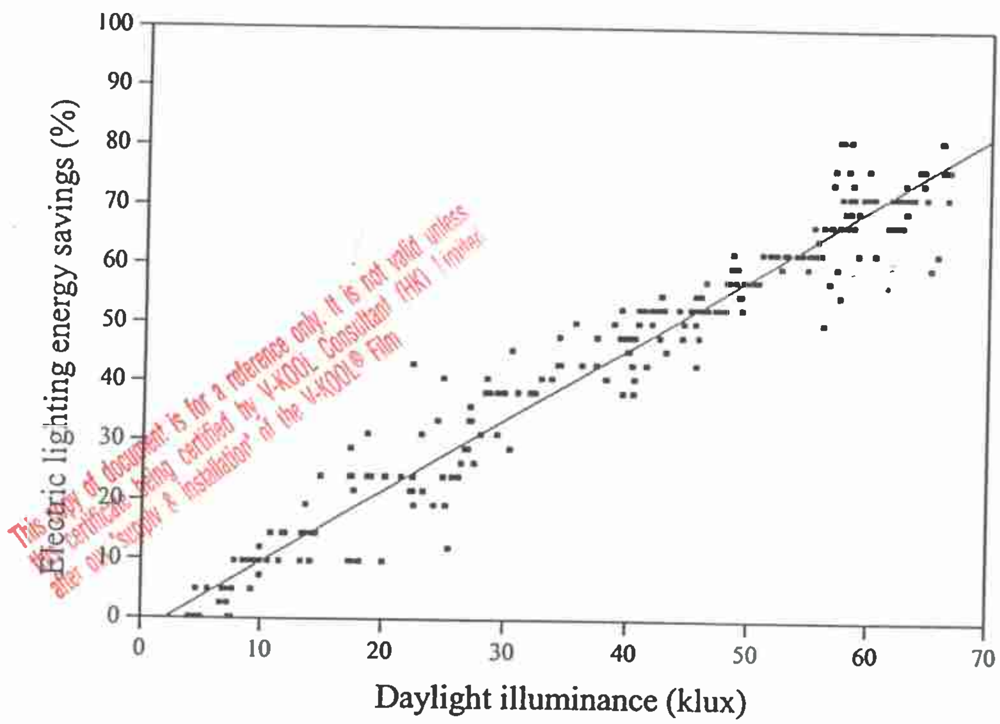

Fig.13 Correlation between daylight availability and artificial lighting energy savings for afternoon period

4.4 A case study

A simple case study has been conducted to get some idea about the likely energy trade-off between the reductions in solar heat gain and daylight availability when the V-KOOL film coating is being used. The case study is based on the cellular office Room 2817 with the window and floor areas of 3.55 and 8.64 m^2, respectively. Assuming an average coefficient of performance of 3 for the chiller plant, the electricity use in cooling energy due to solar heat gain through the windows was computed accordingly. Using Equations 1 and 2, and the measured daylight availability data, the photoelectric lighting control savings were determined (electric lighting savings during lunch-time was excluded). Table 2 summarises the overall electricity expenditures. As V-KOOL can minimise the solar heat gain but gently reduces the visible light transmission, the cooling energy saving and the penalty in electric are 0.59 and 0.113 kWh, respectively. The overall effect was a reduction of electric energy use of 0.477 kWh (0.055 kWh/m^2) for a cellular office facing west.

Table 2 Overall daily electric energy use (per unit floor area)

	Without V-KOOL	With V-KOOL	Saving/penalty*
Cooling energy (solar heat)	1.53 kWh ($0.177 kWh/m^2$)	0.94 kWh ($0.109 kWh/m^2$)	0.59 kWh ($0.068 kWh/m^2$)
Savings in electric lighting	0.398 kWh ($0.046 Wh/m^2$)	0.285 kWh ($0.033 kWh/m^2$)	-0.113 kWh ($-0.013 kWh/m^2$)

* -ve value indicates penalty

5. Summary

Field measurements of the V-KOOL solar control film performance in an air-conditioned office building with photoelectric lighting controls were conducted. The solar heat gains, indoor daylight illuminance levels of two cellular offices and their electric lighting energy consumption with and without the V-KOOL film on the window glass were recorded and compared. Using the V-KOOL film coating, solar heat rejection was up to about 30% for pure diffuse solar radiation. In the afternoon, when the west-facing facade recorded certain amount of direct components, over half of the solar heat would be rejected. This indicates that the solar heat rejection of the V-KOOL solar film depends on the amount of solar radiation received. The hourly daylight illuminance data have been analysed. Unlike the measured solar heat gains, the reduction in visible transmittance due to V-KOOL film coating was rather constant regardless to the quantity of illuminance recorded. It was found that the visible transmittance of the film was around 76%. The correlation between the daylight availability and the electric lighting savings was evaluated. Two sets of data measured in morning period containing mainly the diffuse components and in afternoon period dominating by direct sunlight were used for the analysis. Two linear correlation equations were formed separately based on these two data sets. It was found that with more diffuse components, more electric lighting savings were resulted in the morning than those in the afternoon for a given daylight illuminance value. With R^2 greater than 0.84 for the two cases, the modelled equations were considered satisfactory. A case study indicated that the overall electric savings due to the V-KOOL solar control film could be in the order of $55 Wh/m^2$ (of the office floor area) per day for the cellular office located at the west perimeter zone base on the field measurement data.

The impacts of the solar film coating on cooling energy requirements and electric lighting loads depend upon attending to the subtle interactions of a large number of architectural aspects and building services systems. To have a more comprehensive picture, more on-site measurements of the actual conditions are required.

6. Suggestions for Further Work

The interactions and relationships among lighting, heating and cooling and their implications for energy consumption in buildings are rather complex. To have a thorough investigation of the overall effects due to the solar control film, a number of items for future study and development are suggested. They are as follows:

Cooling energy

In subtropical Hong Kong, solar heat gain accounts for a significant proportion of building cooling load. The savings due to the reduction in solar heat can be reflected in air-conditioning electricity use. Since centralised HVAC system is commonly used in commercial buildings, it would be impossible to identify precisely such savings based on the two cellular offices. To obtain reliable information on cooling energy, it is suggested to install small air-conditioning units such as window type or split type air-conditioners for individual cellular offices used for field measurements. Alternatively, it is suggested to install the solar film for the whole floor (e.g. 28th floor). We then log the air-conditioning load from the air-handling unit and the artificial lighting energy for the perimeter zones in two floors (one with and the other without the solar control film). The logged air-conditioning and electric lighting energy expenditures would provide more reliable information.

Bahaviour/attitude of users towards daylighting

Daylight makes an interior space look lively and more attractive. However, some people may block the daylight using internal shading device all the time. Visual comfort, sometimes, is a psychological aspect rather than an architecture issue. It will be useful to conduct a survey of user behaviour and preference regarding the use of solar control film in air-conditioned office buildings.

Working plane layout and room parameters

The position and orientation of working plane strongly affect the use of the solar control film. In terms of energy efficiency, working plane should be located near to the window facade. However, users may feel thermal and visual discomforts due to the built up contrast if their working areas are very near to the windows. The fenestration areas, solar and light transmittances, shading devices and the location of working places are important parameters affecting the air-conditioning and electric lighting energy expenditures. Further study on these areas is needed.

Glare due to daylight

The amount of daylight entering a building is mainly through window openings. However, windows are potential sources of glare because they occupy a large portion of the visual field. In the presence of sunlight, this problem is even more complex. The effect of window size on discomfort glare based on occupant's appraisal and using established glare prediction algorithms should, therefore, be examined.

Internal shading devices

The use of manually controlled venetian blinds may reduce the energy savings from photoelectric control systems. The venetian blinds may provide more shading than is really necessary, for example the blinds are often pulled all the way down to block out direct sunlight. Also, shading is not reduced once the conditions change. It is necessary to conduct investigation into the use of other blind types and their dynamic interactions with V-KOOL solar control films and lighting control systems, which can save more energy and provide a better visual and thermal environment.