Total Energy Performance of Atria with Daylight

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The current design trend for commercial buildings in Hong Kong is to introduce shopping arcade at the lower floors and provide atrium with daylight. If daylight is properly utilised, the electrical lighting energy can be saved. On the other hand, introduction of atrium will allow the entrance of solar heat which will introduce extra cooling load to the air-conditioning systems. What would be the overall energy performance of a daylighted atrium? Could the saving on electrical lighting power compensate the additional energy expenditure on cooling due to the introduction of atrium? This paper presents a study carried out for three different types of atria in Hong Kong. Energy performance of atria with assumed daylight-linked lighting control is analysed using Computer simulation programs Ecotect and HTB2. The field-measurement of average daylight factor was conducted in real atrium site to validate the simulation results. Different design alternatives on lighting strategies, fenestration glazing types, as well as skylight area and shapes were investigated. The overall energy performance, evaluated with respect to a base case design (same atrium covered with an opaque roof), showed that the daylight-linked lighting controls can provide an annual lighting energy saving around 66% for the three atria studied.

The annual total energy consumption of atrium spaces with daylight-linked lighting controls were about 20 to 40% higher than the base case design. This indicates that energy savings from artificial lighting generally cannot compensate the daylight-induced cooling penalty. However, when the glazing type and glazing area of atrium roof light were varied, the result showed that it is possible that the overall energy expenditure on lighting and air conditioning could be smaller than the base case.

Keywords: Atrium, Lighting, Daylighting, Energy

List of Abbreviations and Symbols

f(E)	the occurrence frequency in percentage of an illuminance E in a year
F_{sav}	fractional energy saving for daylight-linked dimming control
F_o	fractional of the working year when daylight alone can achieve the required indoor design illuminance using on/off control
I_d	summation of the products of frequency f and its corresponding illuminance in mid-point of each 1000 lx interval up to E_o (lx)
E_o	required outdoor daylight illuminance which will provide adequate indoor illuminance (lx)
W_{sav}	annual energy saving from artificial lighting (W)
FLPL	full lighting power loading in atrium space (W)
H_d	daytime operating hours of the artificial lighting (hr)
$H_{c\text{-}d}$	operating hours of the artificial lighting at daytime in cooling seasons (hr)
$H_{c\text{-}n}$	operating hours of the artificial lighting at night in cooling seasons (hr)
$F_{c\text{-}sav}$	fractional of annual energy saving of daylight-linked dimming control in cooling seasons
W_{ac}	energy input to the chiller compressor (W)
Q_c	cooling loads obtained by HTB2(W)
COP	coefficient of performance of air-conditioning system
SHGC	solar heat gain coefficient
SC	shading coefficient

Introduction

In Hong Kong, the building professional has become increasingly concerned about energy consumption in buildings and its likely adverse effects on the environment. This perception of energy and environmental issues are due to the rapid growth of energy demand in buildings in recent years. The government census data indicated that the commercial sector has become one of the largest electricity end-users in Hong Kong [1], and a significant amount of electricity consumption is for the building air-conditioning systems and the artificial lighting. Efficient use of electricity in buildings can have both economic and environmental benefits.

The atrium is one of the common architectural features for commercial buildings and shopping arcades in Hong Kong. The atrium creates a dynamic and stimulating interior. The atrium roof light can be an effective source of illumination. Chung [2] noted that the outdoor horizontal illuminance in Hong Kong exceeds 10,000 lx for over 80% of the normal office hours in a year. The development of daylight-linked photoelectric lighting control systems helps to realise the saving of electrical lighting power.

The atrium facilitates energy saving in two ways. Firstly, the natural daylight reduces electricity consumption of artificial lighting. Secondly, less heat dissipation from lighting fittings reduces the cooling load. Nevertheless, the atrium skylight not only allows the entrance of solar heat to the interior space, but also enhances the conductive heat gain due to relatively high U-values of glazing material as compared to standard roof constructions. The trade-offs between beneficial natural daylight and unwanted solar heat has always been a perplexing problem for design engineers.

Franzetti et al [3] demonstrated that the interaction between artificial lighting and thermal load of office building with side lit windows by mean of computer software CA-SIS. Lam and Li [4-7] provided a simple method for estimating the energy saving through side lit windows and determined the possible cooling penalty by means of average solar heat gain factor. However, these studies have been conducted only on side-lit room in office buildings. There has been no study on the overall energy performance of atrium building to include both artificial lighting and air-conditioning systems. The present study attempts to investigate the overall energy performance of atrium buildings using computer simulation.

Evaluation of Energy Performance of Atria

Overall Energy Performance

Three generic atria in Hong Kong shopping arcades were selected for study and they have different skylight geometries. The daylight factor values of the atria were obtained by computer software Ecotect. Ecotect is a comprehensive and innovative building analysis software. It has

3D feature and it is capable of carrying out simulation study for solar analysis, lighting simulation, daylight calculation, thermal performance analysis, cost analysis, etc. The most significant feature is its interactive approach. For example, add a new window in the model building and immediately one can see its thermal effect, changes in daylight factor, solar radiation heat gain and overall building cost. Its limitation is that it does not have the Hong Kong weather data and is not suitable for thermal analysis of Hong Kong buildings. Computer program HTB2 was used to carry out transient thermal simulation. HTB2 is a powerful tool for simulating the thermal performance of a building. It has limitations, but it has the local weather data for Hong Kong and is therefore a useful tool for thermal simulation of buildings in Hong Kong. The opening hours of the atria are assumed to be 10 am to 10 pm. A field-measurement on average daylight factor of atrium space was conducted to validate the Ecotect simulation results. A base case is used for comparing the energy performance of atrium space with different design alternatives. Fig 1 is a planning of the present investigation work.

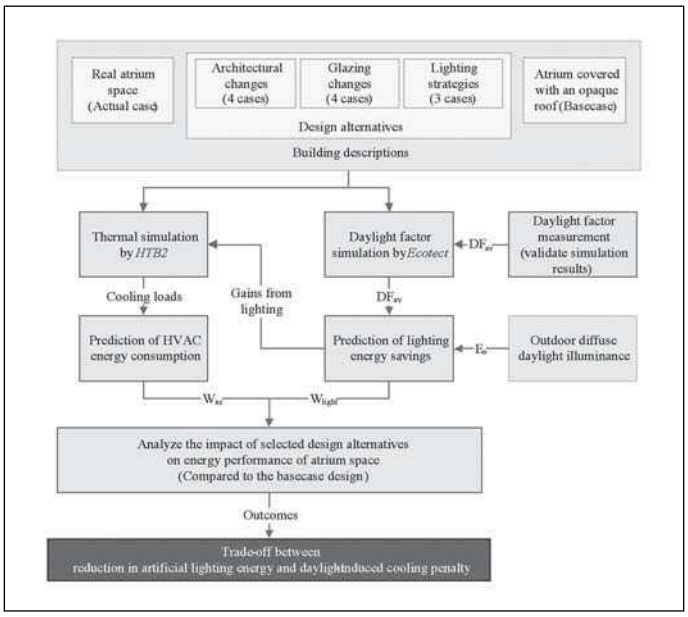


Figure 1 – Outline of Investigation

Description of the Sites

Three atrium spaces in shopping arcades in Hong Kong were selected for investigation. The details of the atria are in Table 1 below;

Atrium	Area(m^2)	Shape	Height(m)	Roof type	Lamp type	No x Watts (estimated total power)
1	90	Circular	16.5 (4 floors)	Flat	LVTH	250 x 35 (8750W)
2	144	Rectangular	5.5 (1 floor)	Pitched	Metal halide	76 x 50 (4560W)
3	243	Rectangular	13 (3 floors)	pyramidal	Metal halide	32 x 125 (4800W)

Table 1 – Details of Three Atria Studied

Prediction of Average Daylight Factor

The computer software Ecotect was used to calculate the average daylight factor in the atria for various design alternatives. A grid of one to two metre spacing were generally adopted in the simulation calculation. The atria are blocked by adjacent buildings. Also detailed knowledge of the atria glazing characteristics and its maintenance condition could not be obtained, all of which will affect the computer simulation. Site measurement was conducted to obtain the average daylight factor to correct the simulation results.

Measurement of Average Daylight Factor

To obtain the daylight factor of an atrium space, simultaneous daylight illuminance indoor and outdoors were to be measured. Currently available daylight photometer has limited cable length and is not suitable for atrium daylight factor measurement. The indoor and outdoor daylight illuminance were measured separately but concurrently.

The outdoor daylight illuminance was data-logged in one minute intervals continuously by digital illuminance metre at the Hong Kong Polytechnic University campus. The indoor daylight illuminance in atrium was measured at floor level at 2 m grid points by digital illuminance metre. In order to ensure simultaneous measurement, the time of each data point in the indoor measurement was recorded. The measurement was undertaken on an overcast day to avoid the effect of the sun. In case the artificial lights in the atrium were switched on during the daytime, a separate indoor illuminance measurement was conducted at night to determine the illuminance contribution from artificial lighting. The actual indoor daylight illuminance in atrium space can thus be determined by the two sets of data.

The Hong Kong Polytechnic University campus is remote from the atrium building sites and the outdoor daylight illuminance collected there are not representative of the outdoor daylight illuminance at the atrium building sites. To improve the measurement accuracy, a number of outdoor daylight illuminance measurements were taken at the atrium building sites. These data were compared with the data logged in the Hong Kong Polytechnic University campus and is used to adjust the logged data (daylight factor measurement data omitted due to constraint on maximum page numbers).

Computer Simulation of Average Daylight Factor

In order to find the average daylight factor for the atria with different design alternatives, a series of computer simulations were carried out by Ecotect. Ecotect can couple with the thermal simulation program HTB2, hence enhances the consistency of modelling between Ecotect and HTB2. Fig 2 to Fig 4 shows the perspective and plan views of three atria modelled by Ecotect.

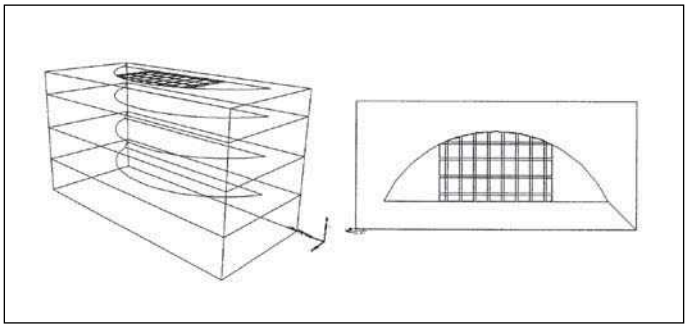


Figure 2 – Atrium 1: Perspective and Plan Views of Atrium with Flat Skylight

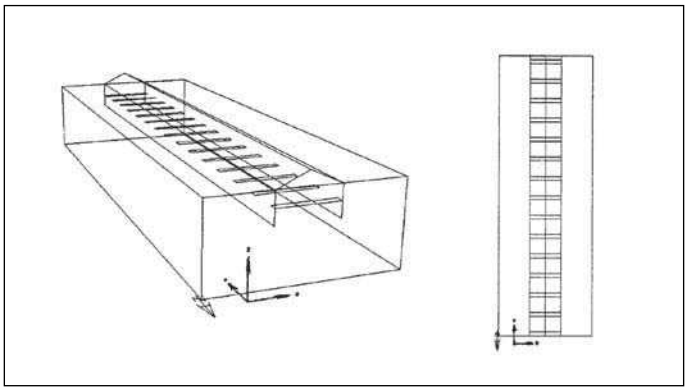


Figure 3 – Atrium 2: Perspective and Plan Views of Atrium with Pitched Skylight

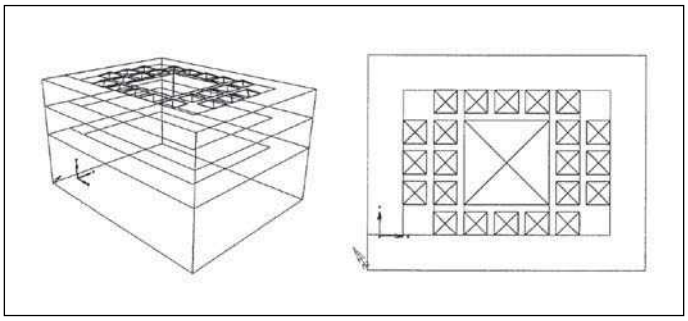


Figure 4 – Atrium 3: Perspective and Plan Views of Atrium with Pyramidal Skylight (The Simulation Results are Omitted Due to Constraint on Maximum Page Numbers)

Solar Radiation and Outdoor Daylight Illuminance

To estimate the total lighting energy savings, we need to obtain the annual daylight illuminance profile of Hong Kong. The Hong Kong Observatory did not have diffuse daylight illuminance data. The Department of Building Services Engineering of the Hong Kong Polytechnic University had carried out hourly global and diffuse solar radiation measurements in 1991. The hourly diffuse solar radiation (kJ/m^2) was used to calculate the outdoor daylight illuminance. It was divided by 3,600 seconds to obtain the average hourly diffuse solar radiation intensity (W/m^2), and then multiplied by the diffuser daylight efficacy 121.1 lm/W obtained for Hong Kong [8,9]. The outdoor daylight illuminance profile for Hong Kong in year 1991 is in Fig 5. These hourly daylight illuminance data were converted to cumulative frequency distribution data in Fig 6 which can be used for lighting energy savings calculation.

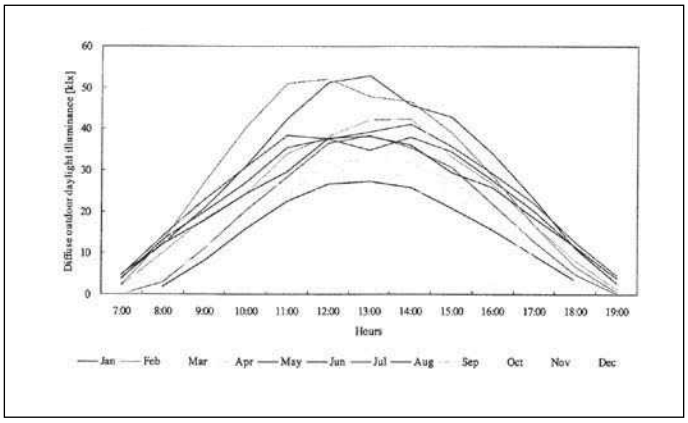


Figure 5 – Hourly Outdoor Daylight Illuminance for Different Months in 1991

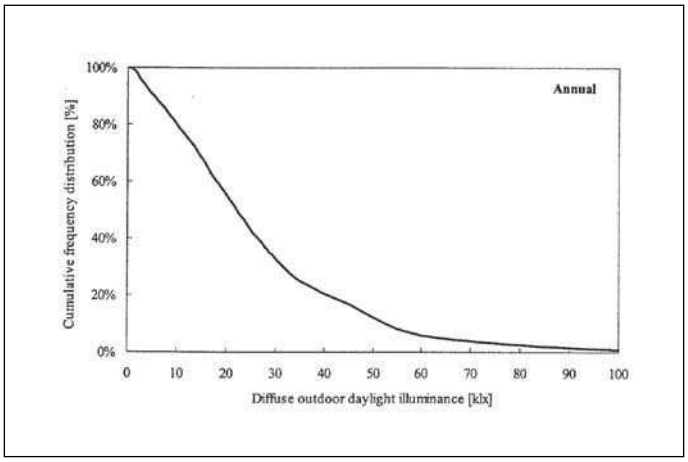


Figure 6 – Cumulative Frequency Distribution of Annual Diffuse Outdoor Daylight Illuminance for Hong Kong (1991)

Calculation of Lighting Energy Saving

The lighting energy saving for daylight-linked on/off control is equal to the fractional savings when daylight alone is adequate to maintain design indoor illuminance. It can be determined from Fig 6 or calculated by the following equation:

$$F_0 = \int_{E_o}^{\infty} f(E)dE \qquad \text{Eqn (1)}$$

When the lighting is dimmable and it is linked to daylight, lighting energy could be saved. Since the lamps will consume a fixed amount of power even if it is operating at its lowest dimming state due to the presence of control gear, it was assumed that 12% of the total electricity is consumed by the control gear, therefore the annual fractional energy saving is:

$$F_{sav} = F_o + 0.88 \frac{I_d}{E_o} \qquad \text{Eqn (2)}$$

The annual frequency distribution of outdoor daylight illuminance for Hong Kong was used to determine the parameter F_o, I_d and E_o with the predicted average daylight factor of atrium space. An indoor design illuminance of 300 lx is assumed which is the value recommended by CIBSE Code of Interior Lighting [10]. Having determined the fractional energy savings for daylight-linked dimming control in a year, the annual lighting energy savings of atrium space is:

$$W_{sav} = FLPL \times F_{sav} \times H_d \qquad \text{Eqn (3)}$$

Sensible Heat Dissipation from Lighting Fittings

The lighting system contributes to the sensible heat gain of the building. The annual sensible heat dissipation from lighting fittings is assumed to be the same as the power consumption by artificial lighting in cooling season (March to November in Hong Kong). The annual sensible heat gain from artificial lighting is defined as follows:

$$Q_{lights} = FLPL \times H_{c\text{-}d} \times (1 - F_{c\text{-}sav}) + FLPL \times H_{c\text{-}n} \qquad \text{Eqn (4)}$$

Thermal Simulation and Energy Consumption for Air-conditioning Systems

The sum of all instantaneous heat gains to the space at any given time is not necessarily equal to the instantaneous cooling load. The main difference between the instantaneous heat gain and space cooling load is caused by thermal storage effect [11]. In order to couple the interrelationship between daylight, artificial lighting and solar heat gain in atrium space as well as estimate the effect on energy consumption of air-conditioning systems, the cooling load needs to be obtained for analysis.

Computer Simulation of Cooling Loads

The computer software HTB2 was used to estimate the annual cooling loads. HTB2 can account for complex time varying climatic and occupation conditions to predict the thermal performance of a building when it is subjected to the influence of outdoor temperature, solar gain, shading, and ventilation and infiltration [12]. The weather data representative of the Hong Kong climate in the software was used for annual cooling energy estimation.

Nevertheless, atrium is known to be subjected to significant temperature stratification due to large solar heat gains through atrium skylight. This temperature stratification influences thermal comfort and increases the energy consumption of air-conditioning systems. To predict the temperature stratification and air flow pattern in atrium space requires Computational Fluid Dynamics (CFD) modelling techniques for accurate and detailed analysis. However, CFD models are not practical for dynamic simulations since they require excessive calculation time [13]. In our case, two main assumptions were made for carrying out the thermal

simulation: (1) Most of the solar radiation falls on the atrium floor and then is converted into cooling loads; (2) the temperature stratification remains in the upper zone of the atrium void at steady state while the air-conditioning system serves the lower, occupied zone only. In addition, the heat gains from lighting fittings were calculated separately in this study, and the occupancy pattern and internal loads are not related to the interaction between daylight, artificial lighting and air-conditioning systems. Therefore the lighting load, occupancy load and internal loads were excluded in the thermal simulations.

Energy Consumption of Air-conditioning Systems

Once the total cooling loads of the atria are obtained, we are able to calculate the total energy consumption of air-conditioning systems. This cannot be simulated by computer software due to inadequate system details for the studied atrium buildings. If the coefficient of performance (COP) of the air-conditioning system is known, the energy consumption of the air-conditioning system can be calculated as follows:

$$W_{ac} = \frac{Q_c}{COP} \qquad \text{Eqn (5)}$$

A typical coefficient of performance (COP) of 3.0 is used to estimate the energy consumption of air-conditioning systems

Eqn (5) predicts the chiller load of the air-conditioning systems only, but fails to give the energy consumption of the air-side equipments and the chilled water pumps. Since the chiller load contributes to the largest portion of the total energy consumption of air-conditioning systems, this energy calculation provided fast results for analysis.

Evaluation of Energy Performance

Selected Design Alternatives

The lighting schemes and atrium characteristics affect the overall energy performance. The atrium shapes, fenestration sizes and glazing transmittance affect the daylight availability and cooling energy performance. These variables may impact on the daylight contribution and heat transfer through atrium skylight [13-15]. With respect to lighting strategies, daylight-linked on/off controls, dimming controls were assessed. With respect to glazing characteristics, four glazing types were investigated, namely, low-E glass, tinted glass, reflective glass as well as double clear glass. Regarding the atrium architectural design, different skylight area and shapes were examined. Table 2 summarises the twelve design alternatives simulated in the computer software and Table 3 provides the glazing characteristics for different types of glazing used in the simulation program.

Case	Lighting strategies	Glazing types	Architectural design
Base case	No control	No fenestration	100% opaque roof
1 (Actual case)	No control	Clear glazing	Original skylight area
2	On/off control	Clear glazing	Original skylight area
3	Dimming control	Clear glazing	Original skylight area
4	Dimming control	Low-E glazing	Original skylight area
5	Dimming control	Tinted glazing	Original skylight area
6	Dimming control	Reflective glazing	Original skylight area
7	Dimming control	Double clear	Original skylight area
8	Dimming control	Clear glazing	Skylight area reduce to 75%
9	Dimming control	Clear glazing	Skylight area reduce to 50%
10	Dimming control	Clear glazing	Skylight area reduce to 25%
11	Dimming control	Clear glazing	Pitched/pyramidal change to flat skylight

Table 2 – List of Alternative Design Cases for Simulation Study

Results and Discussion

Lighting Energy Savings

Table 4 gives the comparison between simulated and measured average daylight factor for three atria. It can be seen that the simulated average daylight factor was greater than the measured results. The simulated average daylight factor of atrium 1 and atrium 2 are 19% and 42% higher than the measured results respectively. An average reflectance of 0.9 was assumed in the simulation which is the default setting for concrete wall with plastering. Since the actual reflectance may be lower in site condition, this assumption may cause an increase on atrium floor illuminance. The simulated average daylight factor for atrium 3 was found 2.75 times higher than the measured value. This may be due to no obstruction from adjacent buildings were simulated apart from reasons given above. The simulated average daylight factors were corrected in accordance with the measurement results.

Based on the simulated daylight factor of atria, the electrical lighting energy saving is calculated and presented in Fig 7 to 9. It shows the annual lighting energy savings of atria under various alternative designs compared with the base case (with opaque roof).

Impact of Lighting Strategies on the Annual Lighting Energy Saving

It can be seen from Fig 7 that both daylight-linked on/off controls and dimming controls can achieve more than 60% lighting energy saving. The daylight-linked dimming control has slightly better saving than the on/off control.

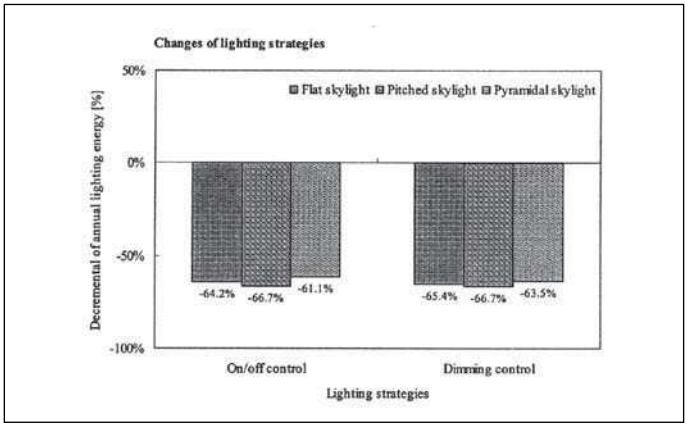


Figure 7 – Annual Lighting Energy Saving for Different Lighting Control Strategy as Compared to the Base Case Design (With Opaque Roof)

Impact of Glazing Types on the Annual Lighting Energy Saving

It can be seen from Fig 8 that the change of glazing types of atrium fenestration generally did not affect the lighting energy saving significantly (with less than 3% difference).

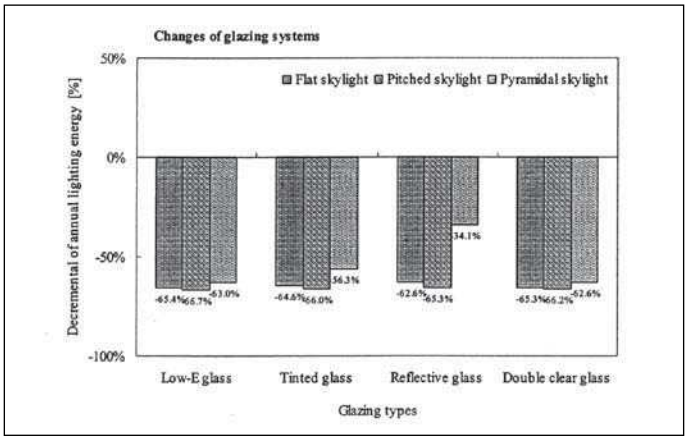


Figure 8 – Annual Lighting Energy Saving for Different Glazing Types as Compared to the Base Case Design (With Opaque Roof)

Glazing		Transmission and absorption coefficients, Angle (10 to 90)									U-value	SHGC	SC
6 mm clear	T	0.83	0.83	0.83	0.83	0.82	0.80	0.75	0.64	0.39	5.82	0.82	0.94
	A	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.11			
6 mm tinted	T	0.49	0.48	0.48	0.47	0.45	0.43	0.39	0.32	0.18	5.82	0.62	0.72
	A	0.46	0.46	0.47	0.48	0.49	0.50	0.51	0.49	0.41			
6 mm low-E	T	0.57	0.58	0.57	0.56	0.55	0.53	0.49	0.40	0.24	3.41	0.61	0.71
	A	0.25	0.25	0.26	0.27	0.27	0.27	0.29	0.30	0.24			
6 mm reflective	T	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.09	0.06	3.25	0.23	0.28
	A	0.65	0.66	0.66	0.66	0.65	0.64	0.62	0.57	0.40			
18 mm double clear	T	0.61	0.61	0.60	0.59	0.58	0.58	0.48	0.36	0.17	3.11	0.7	0.81
	A	0.28	0.28	0.29	0.29	0.30	0.30	0.32	0.31	0.27			

Table 3 – Glazing Characteristics for Different Types of Glazing Used in the Simulation Program

Descriptions	**Atrium 1 (Flat skylight)**	**Atrium 2 (Pitched skylight)**	**Atrium 3 (Pyramidal skylight)**
Field-measurement results			
Site conditions	4.96%	11.98%	2.26%
Simulation results			
Clear glass (Actual case)	5.91%	16.97%	8.48%
Low-E glass	5.74%	16.22%	7.97%
Tinted glass	3.93%	9.80%	3.69%
Reflective glass	2.28%	6.55%	1.58%
Double clear	5.40%	14.79%	7.00%
75% skylight area	3.87%	10.83%	7.24%
50% skylight area	2.71%	9.20%	6.21%
25% skylight area	2.62%	6.48%	4.94%
Flat skylight	–	24.32%	13.77%
Corrected results			
Clear glass (Actual case)	4.96%	11.98%	2.26%
Low-E glass	4.82%	11.45%	2.12%
Tinted glass	3.30%	6.92%	0.98%
Reflective glass	1.91%	4.62%	0.42%
Double clear	4.53%	10.44%	1.87%
75% skylight area	3.25%	7.65%	1.93%
50% skylight area	2.27%	6.49%	1.66%
25% skylight area	2.20%	4.57%	1.32%
Flat skylight	–	17.17%	3.67%

Table 4 – Comparison between Measured, Simulated and Corrected Average Daylight Factor

Impact of Skylight Area and Shapes on the Annual Lighting Energy Saving

From Fig 9, the lighting energy saving by daylight-linked dimming control did not vary significantly with either a change of the skylight area or the shape. This may be explained by the fact that although a reduction of skylight areas will reduce the daylight factor, the daylight illuminance is still sufficient to provide adequate illuminance so that electrical lighting is not required.

Effect of Designed Lighting Level on the Annual Lighting Energy Saving

All the above annual lighting energy saving were based on a designed indoor illuminance level of 300 lx. If the designed indoor illuminance level were increased, what is the likely outcome of annual lighting energy saving? Calculation has been carried out for different designed indoor illuminance level and the result is presented in Fig 10.

It can be observed that as the designed indoor illuminance increases, the percentage lighting energy saving reduces which is to be expected. However the percentage reduction is small compared to the increase in illuminance level. For a triple increase in indoor illuminance from 300 lx to 900 lx, the reduction in lighting energy saving is 10% for atrium 1, 4.7% for atrium 2 and 25% for atrium 3. The largest reduction in atrium 3 is due to its small daylight factor. We can conclude that for large daylight factor, the daylight is plentiful, hence having a higher indoor design illuminance would not need much supplementary lighting. For small daylight factor, however, having a high indoor designed illuminance calls for a larger amount of supplementary lighting.

Overall Energy Performance

Impact of Lighting Strategies on the Atrium Overall Energy Consumption

Fig 11 illustrates the effects of the type of lighting installation on the annual total energy consumption of atria. As compared with the base case design, the annual total energy consumption may be positive or negative. Atrium 1 has an energy saving from 47 to 49% when installed with a daylight-linked lighting control system. The annual total energy savings in atrium 1 is attributable to high installed lighting power density.

For atrium 2 and 3, the total energy consumption with daylight-linked lighting control were 21 to 40% higher than the base case design. Although the potential lighting energy saving of daylight-linked lighting control are up to 67% (Fig 7), the overall energy consumption of atria are higher than the base case with an opaque roof. This indicates that the energy saving from artificial lighting cannot compensate the daylight-induced cooling penalty.

When the indoor designed illuminance is increased, supplementary electrical lighting will be increased and there will be some reduction of lighting energy saving (about 5 - 15%). The solar heat gain, however, is unchanged. This will result in a small increase in overall energy consumption.

Impact of Glazing Systems on the Atrium Overall Energy Consumption

Fig 12 demonstrates the effect of the glazing types on the annual total energy consumption. There is a total annual energy saving between 52% and 57% compared with the base case for atrium 1 no matter which type of glazing is used. For atrium 2, the reflective glass has the

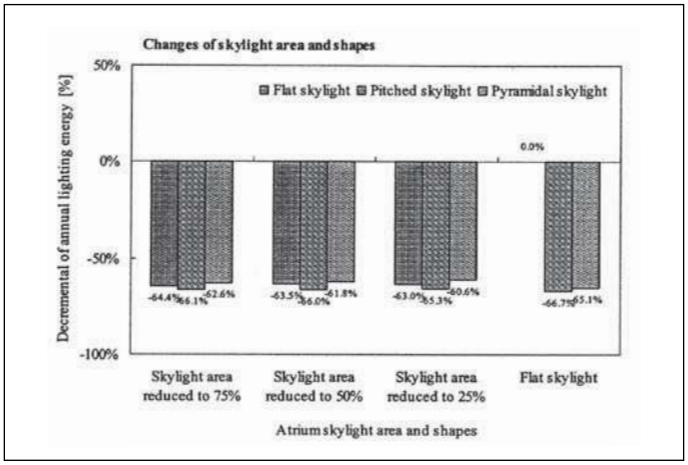


Figure 9 – Annual Lighting Energy Saving for Reduced Skylight Area as Compared to the Base Case Design (With Opaque Roof)

highest energy saving. For the other glazing types, the energy saving from lighting balances the energy expenditure on solar heat gain. For atrium 3 there is still an energy penalty of 12% and 14% for low-E glass and tinted glass. The double clear glazing increased annual total energy consumption from 3.6 to 19% in both atria 2 and 3.

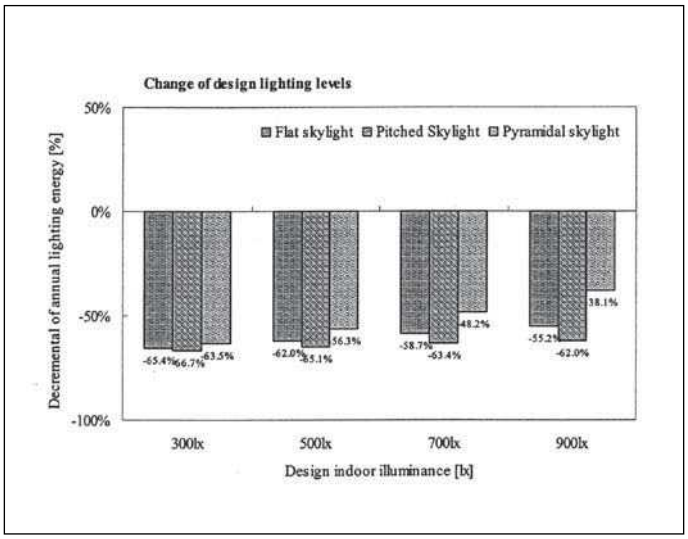


Figure 10 – Lighting Energy Savings under Different Designed Indoor Illuminance

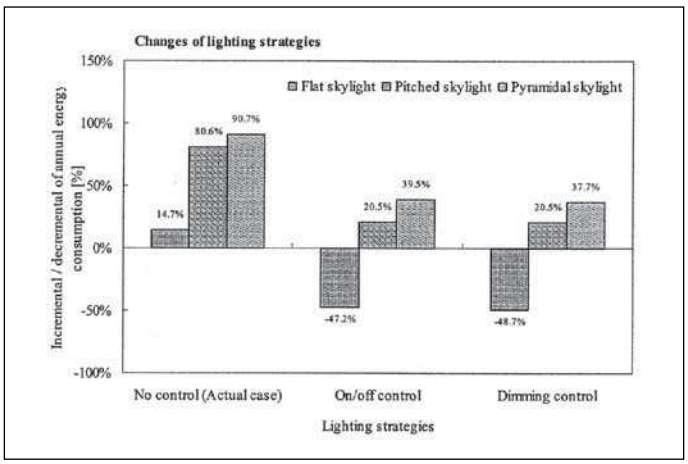


Figure 11 – Annual Total Energy Consumption for Different Lighting Control Strategy as Compared to the Base Case Design (With Opaque Roof)

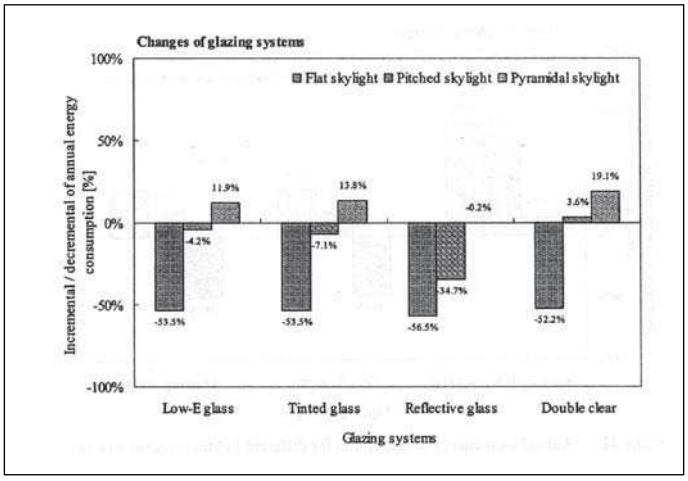


Figure 12 – Annual Total Energy Consumption for Different Glazing Type as Compared to the Base Case Design (With Opaque Roof)

Impact of Skylight Area on the Atrium Overall Energy Consumption

Fig 13 shows the effect of fenestration area of atria on the annual total energy consumption compared with base case design. Since the gains from lighting dominated the annual cooling loads of atrium 1, the reduction in skylight area has very moderate effect on the total energy consumption. For atria 2 and 3, reducing the skylight area resulted in the reduction of overall energy consumption. It can be observed that the annual total energy consumption with 75% skylight area was about 8.6 to 22% higher than the base case design. With 50% skylight area, there is still a 1.4% of energy penalty in atrium 3 but a 7.4% energy saving in atrium 2. With 25% skylight area, there are 29% energy savings for atria 2 and 23.5% energy saving for atria 3.

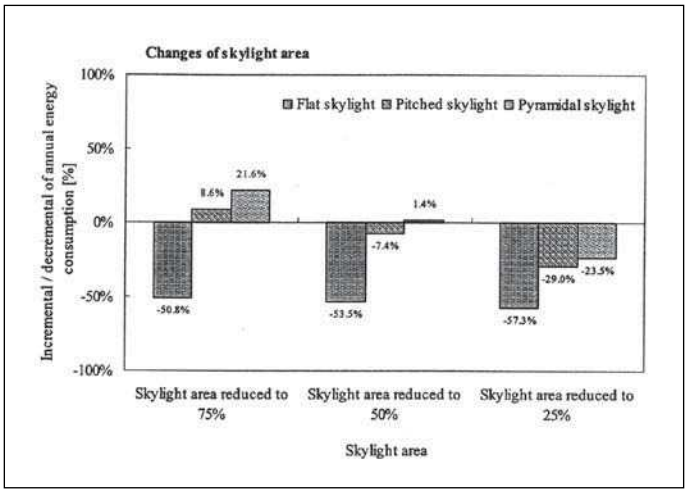


Figure 13 – Annual Total Energy Consumption for Different Skylight Aperture as Compared to the Base Case Design (With Opaque Roof)

Conclusion

Energy performance of atria with daylight-linked lighting control is studied by using simulation calculation on three real atria. A base case with opaque roof serves as a reference for comparison. Alternative design using different lighting strategies, glazing types, skylight areas and skylight shapes were investigated. The results show that:

- The daylight-linked lighting controls can provide about 66% lighting energy savings. The percentage saving is higher if lighting energy for night time is excluded.
- Dimming control has slightly more energy saving potential than the on/off control.
- The lighting energy saving would not differ significantly with changing glazing types or reduced glazing area.
- The annual total energy consumption of atria with daylight-linked lighting controls was found to be 21 to 40% higher than the base case design. This shows that energy savings from artificial lighting cannot compensate the daylight-induced cooling penalty.
- Double clear glazing can reduce the cooling energy by about 24 to 44%, low-E glazing by about 30 to 47%, tinted glazing by about 32 to 48%, and reflective glazing by about 55 to 63%. This indicates that the glazing systems play an important role in controlling the solar radiation through atrium skylight.
- Reducing the skylight area will have substantial reduction in annual cooling energy but do not affect the daylight availability.

Architects and designers should take note that due to the high outdoor daylight profile in Hong Kong, daylight availability in atrium is high even for a small daylight factor. It is advisable that atrium skylight should be designed to limit the solar radiation heat gain to have maximum energy benefit. This can be achieved by using various types of solar control glass such as low-E glass, tinted glass or reflective glass. The aperture area

could also be reduced by proper skylight design or shading. Shading in the west orientation is particularly useful because the afternoon sun will add significantly to the space cooling load when the ambient temperature is already high in the afternoon.

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