INFLUENCE OF HIGH PERFORMANCE FAÇADE ON HEATING/COOLING LOAD IN OFFICE BUILDINGS IN LONDON AND HONGKONG

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ABSTRACT

Office buildings are responsible for a significant amount of carbon emissions. A possible strategy for reducing emissions from this source in both hot and cold climates might be to specify high performance facades. This paper reports on an investigation using Tas on the merits of using high performance facades on office buildings in London and Hong Kong both of which have a high density of office buildings but quite different climates. The results show that whereas U-value has a marginal/negative effect on energy usage at these locations the influence of g-value is somewhat more positive. Moreover, by selecting facades which minimise energy demand when solar irradiations are low and maximising the use of, for example, solar energy and air/ground source heat pumps at other times could significantly reduce carbon emissions from office buildings.

INTRODUCTION

There is a global effort to reduce greenhouse gas (GHG) emissions, chiefly carbon, because of climate change, described as the greatest long term challenge facing the world. The UK has responded strongly and is aiming to reduce 80% of its GHG emissions, relative to 1990 levels, by 2050, using a number of measures including energy efficiency (DCLG 2008). Likewise, Hong Kong, along with other Asia Pacific regions, is aiming to reduce carbon emissions by reducing 25% of its energy consumption relative to 2005 levels by 2030 (Hong Kong Environment Bureau 2007).

In the UK, almost half of carbon emissions come from the use of buildings (27% from homes and a further 17% from non-domestic buildings). Hong Kong is a commercial city with limited industrial operations and buildings account for over half the total energy consumption (19% residential and 37% commercial). For obvious reasons, early efforts to reduce carbon emissions in the UK were largely focused on domestic buildings. But more recent efforts have concentrated on non-domestic buildings, which would also seem to be pertinent to Hong Kong.

Office buildings are an important type of non-domestic building and would appear to be an obvious sector to tackle given that the energy consumed by these buildings is currently the second highest of the non-domestic building sector at around 17% (Pérez-Lombard, Ortiz et al. 2008). Moreover, in London, office buildings account for the highest percentage of the total non-domestic building floor space provision. According to Choudhary (2012) this is expected to increase by about 35% by 2050.

Given that around 54% of the total energy consumed in office buildings is required for heating and cooling (Pérez-Lombard, Ortiz et al. 2008), in Hong Kong space conditioning actually accounts for around 50% of energy consumption in office buildings (EMSD 2012), it would seem reasonable to assume that the façade being the barrier between the indoor and outdoor environment has a crucial influence on total energy usage and hence carbon emissions from these structures. One possible way of reducing energy usage in office buildings at both locations might be to specify high performance insulation materials and glazing products that have been developed (Jelle 2011). The use of these materials in curtain walls allows designers to provide thin and well insulated façades with high window-to-wall ratios. For example, vacuum insulation panels are able to achieve an overall *U*-value of 1.1 W/m^{2}K with a window-to-wall ratio of 0.7. Increasing the level of insulation in cold climates should reduce conductive heat loses thereby helping to reduce the energy required for heating. In hot climates this measure should reduce conductive heat gains thereby reducing the energy required for cooling. Yet, the studies that have been carried on office buildings in both cold and hot climates appear to provide conflicting results.

For instance, Pikas et al. (2014) investigations involving a generic single floor of an office building in Estonia where the climate is cold found that the most cost and energy efficient façade would be one with a small window to wall ratio, argon filled triple glazing and walls with 200 mm thick insulation with a U value of 0.16 W/m^{2}K. Grynning et al. (2013) investigated the energy performance of windows in a Norwegian office by varying both the *U* and *g* values of glass, where g-value indicates the share of the incoming solar energy converted into heat inside a building. G-value is expressed as a number between 0 and 1, where lower values mean less solar heat transmission and generally accounts for the whole window including the effect of the frame. Grynning et al. (2013) found that despite the cold weather conditions the cooling demand was high. But a study conducted by AECOM (2011) for UK conditions suggested that lowering the U-value from the currently recommended value of 2.2 W/m^2K for windows/curtains walls would have little benefit.

The benefits of increasing insulation levels in office buildings in warm/hot climates are equally unclear. McMullan (2012) states that specifying envelopes with high insulation levels should reduce energy usage since this reduces heat infiltration. This is confirmed in a study conducted by Aktacir et al. (2010) in Adana, Turkey, which has hot and humid summers and warm winters. These authors found that the best insulated walls decreased the design cooling load by up to 33%. However, Kim et al. (2009) found that good envelope insulation did not provide much energy savings in hot climates. In Botswana where the climate is hot and dry, Masoso et al. (2008) found that at a certain combination of cooling-set temperature and internal gains there exists a 'point of thermal inflection' where 'the higher the *U*-value the better'.

The principal aim of the work reported in this paper was to discover if the use of high performance facades would help reduce carbon emissions from office buildings in London and Hong Kong, both of which have a high density of office buildings but quite different climates.

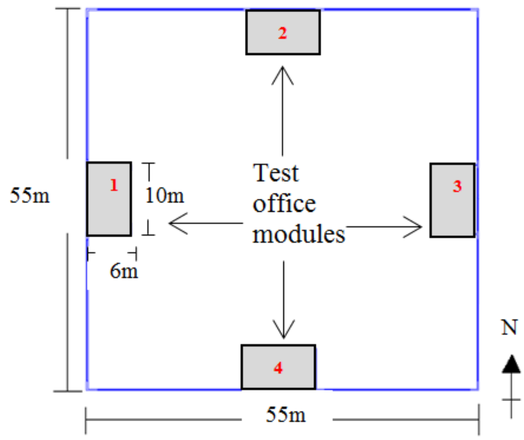
The energy required for heating and cooling in this work was estimated using a well-known dynamic simulation tool called Tas (EDSL 2012). The following provides details of the simulations that were carried out.

CALCULATION METHODOLOGY

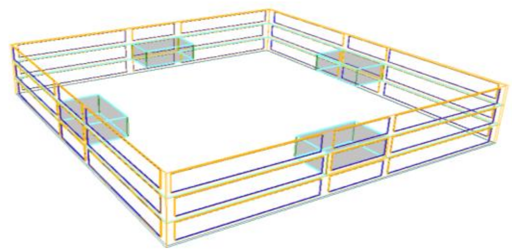
Dynamic simulation: EDSL TAS

Tas is a commercially available software, developed by EDSL. It is accredited by the UK government and can be used to estimate the annual load due to heating, cooling, lighting and ventilation of buildings. Tas models hourly energy requirements and can be used to analyse the performance of whole structures. But in this work only the performance of four single office spaces was analysed.

Figure 1 shows the layout of the building used in this work. It is essentially a square, three-storey structure with an area 55m×55m per floor and floor to ceiling height of 3m. The structure is actually a simplified model of a tall, multi-storey office block and assumes that all the floors apart from the top and the bottom consume similar amounts of energy. Energy usage was assessed by considering the performance of four perimeter offices: 1, 2, 3 and 4, 6m deep × 3m high × 10m long, which were assumed to be located on the middle floor and face respectively West, North, East, and South. It was assumed that the long face forms the external façade and the window to wall ratio is 0.7. The remaining three sides of the room are internal walls, and, as such, the effect of adjacent offices on the performance of the test offices are minimal.



(a)



(b)

Figure 1 TAS building model (a) plan (b) isometric

Table 1 shows values of the other test parameters assumed in the simulations. The standard ventilation rate and internal gains were taken from CIBSE Guide A (CIBSE 2015) assuming the density of occupation is $12m^2$ per person. The overall *U*-value of the façade was assumed to vary between 1.2 and 2.6 W/m^2K. The higher value was selected based on recommendations in Part L2A of the UK Buildings Regulations (DCLG 2010) which states that the U-value of curtain walling should in general not exceed 2.2 W/m^2K but can be as high as 2.7 W/m^2K in buildings with high internal gains. The lower value is based on manufacturer's literature which shows that walling with a U-value of 1.1 W/m^2K and lower is now available. Three levels of g-value, namely 0.3, 0.4 and 0.5, were investigated in this study. All the glazing was assumed to be low-e double glazing.

The effect of latent heat was not considered in the simulations.

Table 1 Test parameters

Model	3m × 10m × 6m; 3m ×10m face is external façade and other faces are internal partitions	
Window to wall ratio	0.7	
Internal gains (W/m^2)	People	6.7
	Lighting	12
	Equipment	15
Ventilation rate	10 l/p/s	
Operating hours	0800 -1800,7 days	
Wall constructions	Glass and spandrel *U*-value	1.2-2.6 (0.2 increment)
	g-value	0.3,0.4,0.5

CLIMATE DATA / CHARACTERISTICS

Tas contains weather files which can be used to carry out the dynamic simulations. But because some anomalies were detected it was decided that it would be better to use data from other sources. Thus for London, the weather data used was taken from CIBSE's Test Reference Year database (CIBSE 2006) whereas for Hong Kong the weather data was obtained from the Energy Plus Website (Energy Plus, 2004).

To guard against gross errors in the dynamic simulations manual checks on the annual and seasonal energy demand based on the heat balance equation (McMullan 2012) were carried out. This required access to values of interior and exterior temperatures in London and Hong Kong as well as values of the incident solar irradiation on windows at these two locations. For convenience the exterior temperatures were obtained from the weather files available in Tas. These show that London has a temperate climate with mild winters and cool summers. Hong Kong, on the other hand, is much closer to the equator and has a humid, subtropical climate with typically warm winters and hot summers. Fig. 2 shows the monthly average temperatures for these two cities. The monthly values were used to calculate the average outdoor temperatures by season shown in Tables 2 and 3 for London and Hong Kong respectively. These tables also include figures for the minimum and maximum seasonal temperatures. Note that in these tables, winter covers the period November-February and summer is the period between June-September. The remaining months are classed as mid-season.

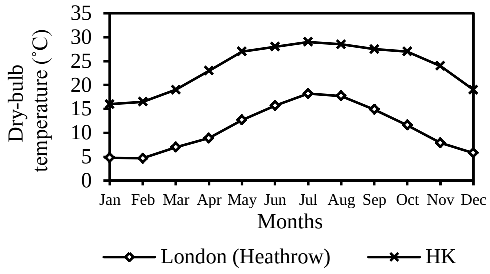


Figure 2 Monthly average temperature profiles for London and Hong Kong

Tables 2 and 3 also include details of the design indoor temperatures, T_{in}, in London and Hong Kong, which are largely similar. The reason for the slightly higher value for Hong Kong in summer is to help reduce energy usage over this period (Yang et al. 2008). These tables also show that the difference between the indoor design temperature, T_{in}, and outdoor mean dry bulb temperature, T_{out}, i.e. ΔT (= $T_{out} - T_{in}$). Note that ΔT is relatively small in Hong Kong compared with London. Moreover, in London the average outdoor temperature is always significantly lower than indoors, as indicated by the negative ΔT values, whereas in Hong Kong this is only the case in winter.

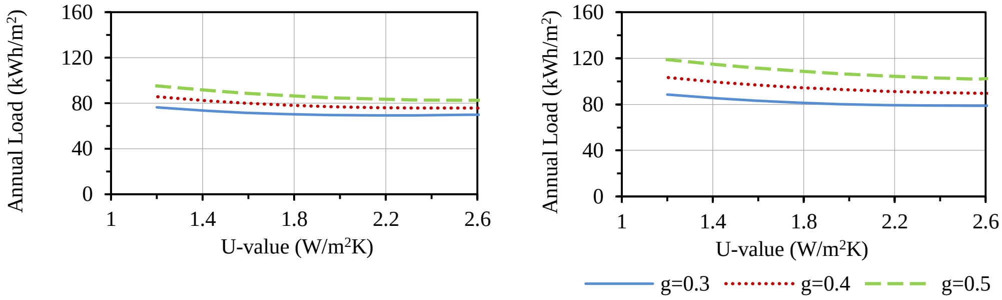
Tables 2 and 3 also show values of the monthly mean daily solar irradiation on vertical surfaces, S_o, averaged over 24 hours (W/m^2). The solar irradiance is a measure of the power per unit area on the Earth's surface produced by the Sun in the form of electromagnetic radiation, perceived by humans as sunlight. For London, these values were determined using the method in SAP (BRE 2012). For Hong Kong, the data is based on a study by Li et al. (2002). The weather data shown in Tables 2 and 3 was not used in the dynamic simulations only the manual checks but has been included here to discuss some of the results obtained.

Table 2 London indoor and outdoor temperatures, solar irradiation, averaged by seasons

London	T_{out} (˚C)			T_{in} (˚C)	ΔT (˚C)	S_o, (W/m^2)			
	T_{min}	T_{max}	T_{av}			N	E	S	W
Winter	0.5	14.5	6.8	22.0	-16.1	14.5	27.1	57.9	27.1
Mid-season	1.7	18.2	10.5	22.0	-11.5	49.4	80.8	100.7	80.8
Summer	9.3	25.7	16.7	22.0	-5.3	70.4	106.6	111.4	106.6

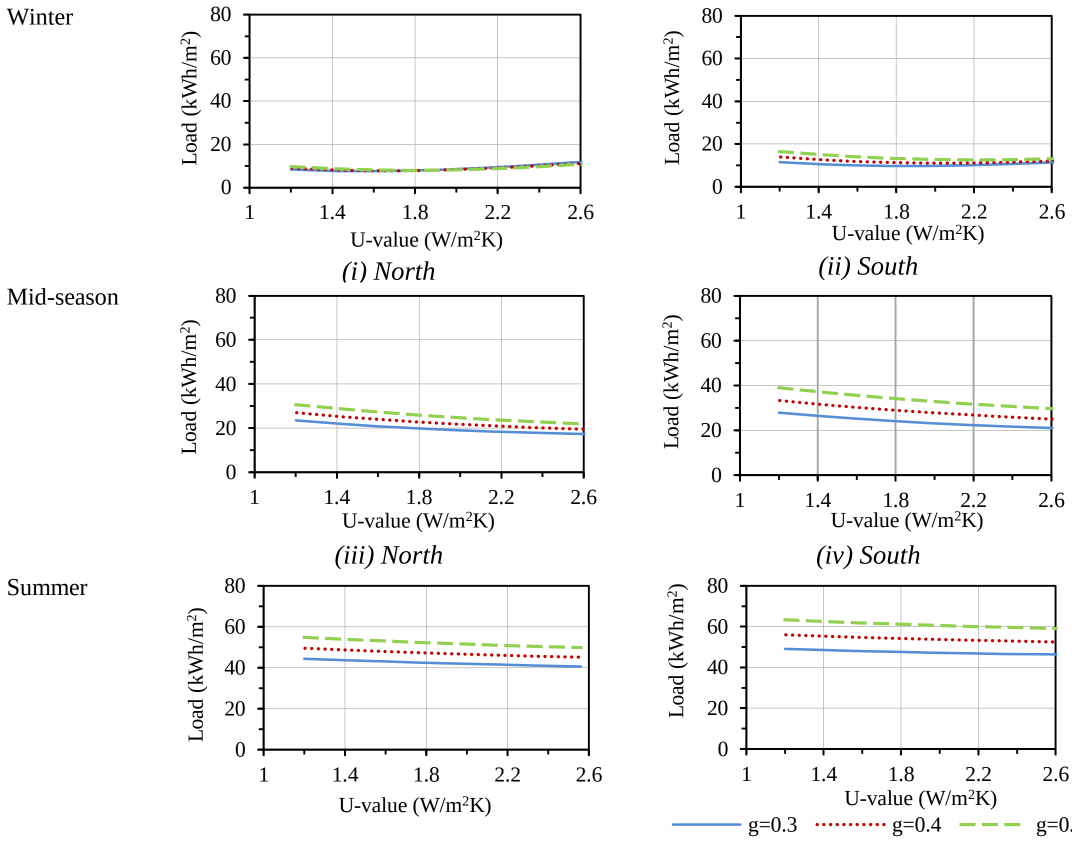
Table 3 Hong Kong indoor and outdoor temperatures, solar irradiation, averaged by seasons

Hong Kong	T_{out} (˚C)			T_{in}(˚C)	ΔT (˚C)	S_o, (W/m^2)			
	T_{min}	T_{max}	T_{av}			N	E	S	W
Winter	13.5	24.1	17.7	21	-2.1	35.4	68.2	118.8	67.7
Mid-season	18.1	28.4	23.2	23	1	45.8	70.8	77.1	77.1.
Summer	24.4	31.9	28.2	25	3.3	57.8	87.0	65.1	89.1



(i)North *(ii)South*

Figure 3 Effect of U and g values on annual load for (i) North and (ii) South facing office in London



(i) North *(ii) South*

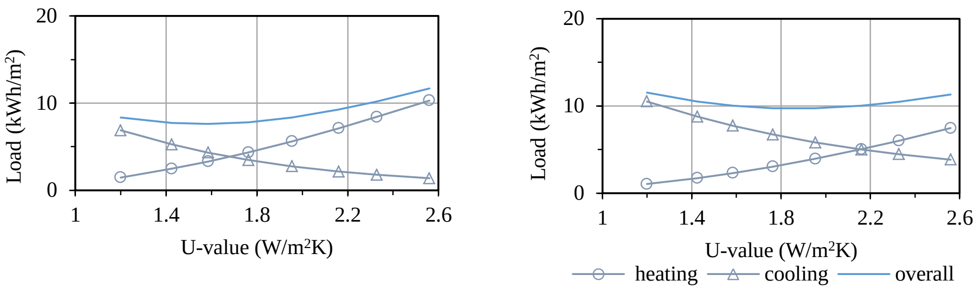
(iii) North *(iv) South*

(v) North *(vi) South*

Figure 4 Effect of U and g values on energy demand by season of North and South facing offices in London

RESULTS & DISCUSSION

The results for London only show the effect on North and South facing offices because these orientations receive the least and most solar radiation respectively. The results for Hong Kong only show the effect on South facing offices since the trends for offices facing in the other directions were found to be similar



(i)North *(ii)South*

Figure 5 Effect of U-value on heating and cooling load for North facing façade, g=0.3, during winter in London

Effect of U-value

London

Figs 3(i) and 3(ii) show respectively for North and South facing offices (respectively office spaces 2 and 4 in Fig 1a) the effect of *U* and various g-values on annual energy demand in London obtained by means of Tas. It can be seen that utilizing façades with low *U*-values in both orientations actually increases annual energy demand.

In order to understand these trends the energy demand by season was determined. Figs 4(i)-4(vi) show the energy required in winter, mid-season and summer by these offices. Here it can be seen that apart from winter (Fig. 4i, 4ii), where it appears the least amount of energy is required when the facade has a *U*-value of 1.8 W/m^{2}K for North facing offices and around 2 W/m^{2}K for South facing offices, in all other cases the energy demand increases with decreasing *U*-value.

An examination of the nature of the energy usage for North and South facing offices in winter shows that they require a mix of heating and cooling (Figs 5i and 5ii). These figures also shows that South facing offices require more cooling than North facing offices over this period.

Further insights are obtained by considering values of the principal factors influencing energy demand, namely

- Conduction heat gain/loss through façade (Q_{cond})
- Ventilation heat gain/loss (Q_{air})
- Internal heat gain (Q_{int})
- Solar heat gain (Q_{sol})
- Heat gain/loss from adjacent spaces due to building heat transfer (Q_b)

Table 3 shows the results for South facing offices in winter (W), mid-season (M) and summer (S) assuming g = 0.5 and *U* is either 1.2 W/m^{2}K or 2.6 W/m^{2}K. The values in the table are the summations of hourly energy demand for these seasons.

Table 3: Effect of U-value on energy demand of South facing offices in London assuming g=0.5

	U	Q_h	Q_c	Q_{cond}	Q_{air}	Q_{int}	Q_{sol}	Q_b
W	1.2	1	15	-23	-19	39	21	-2
	2.6	5	7	-40	-19	39	21	1
M	1.2	0	38	-21	-13	40	36	-4
	2.6	1	29	-32	-13	40	36	-2
S	1.2	0	61	-14	-4	40	43	-3
	2.6	0	57	-20	-4	40	43	-1

Note that Q_h and Q_c represent respectively the heating and cooling load in kWh/m^2. Also, Q_b, which measures the heat gain/loss through internal building elements e.g. walls, floors, ceilings etc and heat temporarily stored in the air (EDSL 2015) is not discussed because its value is small compared with other components of the heat balance and does not affect overall trends.

From Table 3 it can be seen that except in winter if the *U*-value is 2.6Wm^2/K (Q_h = 5 kWh/m^2) there is generally only a cooling demand. This is despite the fact that the average outdoor temperatures are lower than those indoors in London throughout the year (Table 2). The results for winter also show there is an increase in energy demand from 12kWh/m^2 to 16 kWh/m^2 when the *U*-value reduces from 2.6 to 1.2 W/m^{2}K. This is because there is a reduction in heat loss due to conduction via the façade, which not only increases the overall energy load but also increases the energy required for cooling.

In mid-season the average temperature difference between indoors and outdoors is smaller and although this reduces the heat loss due to ventilation, Q_{air}, from -19 kWh/m^2 to -13 kWh/m^2. The conduction heat losses are also lower. Thus in the case of facades with a U-value of 2.6 W/m^{2}K the conduction heat loss reduce from -40 kWh/m^2 to -32 kWh/m^2. Moreover, because solar irradiation levels are higher during mid-season compared with winter (Table 2), the heat gain from solar irradiation, Q_{sol}, increases from 21 kWh/m^2 to 36 kWh/m^2. The net effect is that more energy is required for cooling despite the fact that the average outdoor temperature is still around 11°C lower than indoors.

In summer the difference between the indoor and outdoor average temperature is lower still at around 5°C and therefore the heat loss due to ventilation, Q_{air}, further reduces to -4 kWh/m^2 but the heat lost due to conduction (Q_{cond}) is also reduced. The sun is stronger during this period and this increases irradiation levels and hence solar heat gains in the building to 43 kWh/m^2, and in turn the overall energy required to regulate building temperatures.

Thus it would seem that under the weather conditions experienced in London the façade traps heat inside the building and the provision of low U-value facades exacerbates this condition, thereby increasing energy demand.

Hong Kong

Figure 6 shows the effect on South facing offices in Hong Kong of U and g values on annual energy demand. It can be seen that lowering the *U*-value has a marginal effect on energy demand.

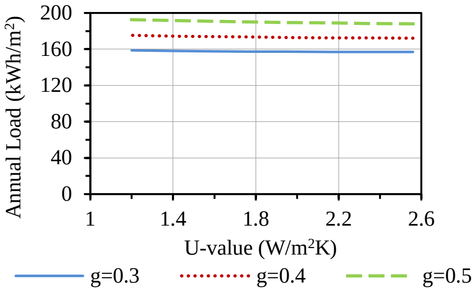


Figure 6 Effect of U and g values on annual energy demand for South facing offices in Hong Kong

As before, in order to understand the results the energy demand by season was determined. Figs 7(i), 7(ii) and 7(iii) show respectively the energy required in winter, mid-season and summer by South facing offices obtained via Tas. The results in Fig. 7(i) show that cooling load increases with decreasing *U*-value.

During mid-season, U-value appears to have no discernible effect on energy demand. During summer, there is a slight decrease in energy demand with decreasing *U*-value (Fig 7iii).

Table 4 shows the energy load breakdown values for winter, mid-season and summer assuming $g = 0.5$ and $U = 1.2$ W/m^{2}K or 2.6 Wm^2/K. It can be seen that there is no heating demand and cooling is necessary all year round. Moreover, it is worth noting that despite the smaller differences between indoor and outdoor temperatures (Tables 1 and 2), more energy is required to regulate temperatures in office buildings in Hong Kong compared with London (Table 3).

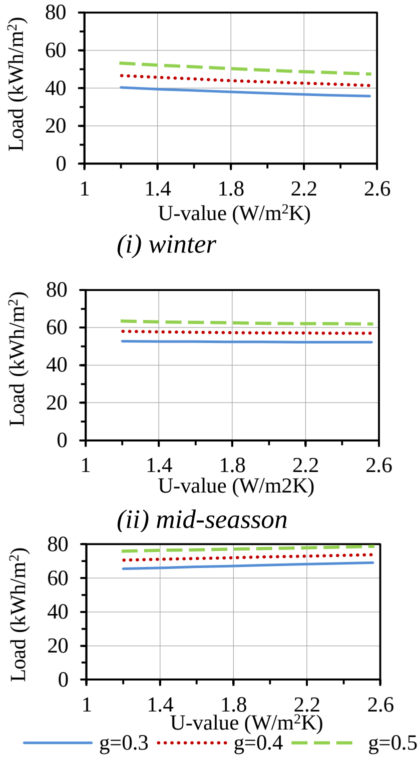


Figure 7 Effect of U and g values on energy demand for South facing office in Hong Kong during (i) winter (ii) mid-season and (iii) summer

Table 4: Effect of U-value on energy demand of South facing offices in Hong Kong assuming g=0.5

	U	Q_h	Q_c	Q_{cond}	Q_{air}	Q_{int}	Q_{sol}	Q_b
W	1.2	0	51	-16	-9	39	42	-5
	2.6	0	46	-23	-9	39	42	-3
M	1.2	0	63	-8	-1	40	33	-1
	2.6	0	62	-10	-1	40	33	-1
S	1.2	0	73	-2	5	40	30	0
	2.6	0	76	1	5	40	30	0

In winter, the provision of better insulated facades decreases conduction heat losses, Q_{cond}, from -23 kWh/m^2 to -16 kWh/m^2 which in turn increases the energy required for cooling from 46kWh/m^2 to 51kWh/m^2. During mid-season, the indoor and outdoor temperatures are virtually identical (Table 2) and this reduces both conduction and ventilation heat losses and increases cooling demand. This would be higher still were it not for the fact that during mid-season South facing office experience a reduction in solar irradiation which reduces solar heat gain from 42 kWh/m^2 to 33 kWh/m^2. From Table 4 it can also be seen that the provision of a low U-value façade has none or very little effect on the various factors influencing energy demand and indeed the overall energy demand.

During summer, outdoor temperatures are on average around 3°C higher than indoors and from Table 4 it can be seen that in the case of facades with a U-value of 2.6 Wm^2/K this results in conductive heat gains, Q_{cond}, as well as heat gains due to ventilation, Q_{air}. However, the sun is at its weakest during this period and therefore heat gains due to solar radiation, Q_{sol}, are at their lowest. Despite that the energy demand is higher than at mid-season. Using a façade with a lower *U*-value reduces conductive heat gains, which reduces overall energy demand.

Effect of g-value

Figures 3(ii) and 6 show respectively for South facing offices in London and Hong Kong the effect of *g*-value on annual energy demand.

Table 5: Effect of g-value on energy demand of South facing offices in London assuming U=1.2 W/m^{2}K

	g	Q_h	Q_c	Q_{cond}	Q_{air}	Q_{int}	Q_{sol}	Q_b
W	0.3	1	10	-22	-19	39	11	0
	0.4	1	13	-23	-19	39	16	-1
	0.5	1	15	-23	-19	39	21	-2
M	0.3	0	27	-17	-13	40	19	-1
	0.4	0	33	-19	-13	40	27	-3
	0.5	0	38	-21	-13	40	36	-4
S	0.3	0	47	-10	-4	40	22	0
	0.4	0	54	-12	-4	40	32	-1
	0.5	0	61	-14	-4	40	43	-3

It appears that *g*-value has a more pronounced effect than *U*-value at these two locations. From the results it can be seen that facades with lower *g*-values have lower energy requirements. From Figures 4 and 7 it can further be seen that this is true for all office orientations and seasons with the possible exception of North facing offices in London during winter. This is probably because North facing offices in London generally require heating during winter whereas cooling is predominantly necessary at other times. The results for South facing offices in London assuming U = 1.2 W/m^{2}K (Table 5) show that energy demand reduces with reducing g-value largely because of the associated decrease in solar gains.

Strategy for minimising carbon emissions from office buildings

The main purpose of this study was to investigate if high performance facades could be used to reduce energy demand and hence carbon emissions from office buildings in London and Hong Kong. However, the results for London show that energy demand actually increased with decreasing U-value. Some reduction in energy usage might be possible by specifying facades with low g-values but these are likely to be modest. Nevertheless, the results in Fig.5 show that in general the lowest energy usage occurs during winter and the highest during summer. Fortunately the solar irradiation levels follow a similar trend (Table 2). This suggests that if the energy usage during winter was minimised by appropriate selection of façade type and the heating and cooling required at other times of the year achieved using air/ground source heat pumps powered by energy derived from photovoltaic cells (PV) significant reductions in both the energy usage and CO_2 emissions should be possible. Clearly there are no CO_2 emissions from electricity generated from PV and air/ground source heat pumps are reported to have a coefficient of performance of 3-5 (Preene and Powrie, 2009).

In Hong Kong the energy usage is more uniform throughout the year. Nevertheless, if a similar strategy was adopted this too would help minimise carbon emissions from office building in Hong Kong.

CONCLUSIONS

1. The energy required for heating/cooling of office buildings in Hong Kong is unaffected by U-value but reduces with reducing g-value of the façade.
2. In London, the use of facades with U-values less than around 2.6 W/m^{2}K increases energy demand but reduces with reducing g-value.
3. The use of high performance facades would appear not to be an appropriate method for reducing the heating and/or cooling demand of office buildings in London and Hong Kong.
4. The results show that a possible strategy for reducing energy usage and carbon emissions would be to select facades which minimise energy demand when solar irradiations levels are at their lowest i.e. winter in London and possibly mid-season in Hong Kong, and using air/ground source heat pumps powered by photovoltaic cells at other times for heating/cooling.

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