Suitability of Dual Skin Glass in Hot Climates

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Keywords

1 = Dual skin facades 2 = Spectrally selective glazing 3 = Energy savings 4 = Integrated simulation approach

Abstract

The concept of dual skin facade was investigated to verify its suitability for Kuwait with respect to its impact on the thermal performance of typical office buildings. A common building trend in Kuwait is to use large glazing areas in the exterior envelop of multi-story office buildings. This trend coupled with a hot long summer and stringent code of practice limits for energy conservation may result in inadequate performance by the HVAC system of such buildings. The technique of dual skin facades may therefore be considered for new designs or for retrofitting existing buildings to overcome some of the problems associated with space cooling of office buildings.

In this study theoretical analysis were applied to study the thermal performance of a typical office building. Computer building models were developed for North-South and East-West orientations. The building was fitted with clear IGU with a certain glazing area. An exterior laminated glass fitted with a spectrally selective film was added to the model to represent the outer skin. A number of computer models were developed to represent cases with different IGU areas in the presence of the outer skin. Hourly simulations were then conducted to determine the annual energy consumption and peak-cooling load for the building. A comparison was then made between the cases considered to assess the thermal effectiveness of the outer glass skin. In addition, simulations were also carried out to determine the acceptable IGU glazing area limit that result in cooling loads within the limit set by the code of practice.

It was found that in the presence of the exterior laminated skin, the maximum glazing area for clear IGU was 60% for both north-south and east-west orientations. For the latter, this is an increase of more than 100% in the IGU glazing area over the base case without the outer skin. In addition, annual energy consumption for the cases with the outer skin and larger IGU areas was found to be the same as that for the base cases with smaller IGU areas and without the outer skin.

Introduction – Challenges in new architectural design trends

Current practices in the architectural design of office buildings have changed dramatically over the past three decades. Nowadays, one of the most common and desirable features of such buildings is large glazing areas. Such trends coupled with stringent energy conservation measures and inappropriate glazing selections, may lead to the designing of buildings in which a comfortable inside condition cannot be maintained. Since the heat gain from external glazing areas contributes directly to a building's cooling and heating loads, the energy codes [1, 2 and 3] were aimed at controlling a building's maximum power demand for the heating, ventilation and air-conditioning (HVAC) system by controlling the heat gain from the different building components.

The present code of practice for energy conservation implemented by the Ministry of Electricity and Water [4] of the State of Kuwait sets out limits for the capacities of air-conditioning (A/C) systems depending on the types of building under consideration. For instance, the limit given for office buildings in terms of wattage per square meter of conditioned floor area is 70 W/m^2 for air-cooled air-conditioning units. This limit, however, increases the probability of having insufficient cooling capacity for buildings with large glazing areas, especially if the glazing type has poor thermal performance. The code further sets general and basic limits on the glazing areas without giving much consideration to the type of building being considered. Although this code was simple to implement and understand, it restricted the designer's flexibility to opt for large glazing areas without adversely affecting the quality of indoor thermal conditions. However, the technological advancements made in the manufacture of high performance glazing may allow the use of larger glazing areas but with an adverse effect on the availability of natural day lighting within the building space. It is mainly for this reason that the concept of dual skin facades is gaining popularity; to impose solar control, maximize the utilization of day lighting, utilization of more neutral glazing configurations with the advantage of increased comfort and productivity of occupants. According to [5], such facades can also include photovoltaic cells (PV) to enhance the energy efficiency of such buildings.

In principal, the concept sounds ideal for hot climates and therefore warrants an investigation to assess its suitability under such conditions. For this purpose, a typical governmental office building was considered for the analysis and was subjected to the climate conditions in Kuwait. A comprehensive building energy simulation program, ESP-r [6], was used to develop the computer model for the building and then to carry out an annual energy analysis. For the office building considered in the analysis, IGU with clear glass was used for the inner skin while for the outer skin; clear laminated glass with a spectrally selective film was used. The spectral property of the laminated exterior shell used in the analysis was extracted from the WINDOW 4.1 [7] program.

Table 1

Base Case building Parameters (east-west orientation)

Shape	Rectangular shape, four-story building
Floor area	1074 m^2
Living space area	4296 m^2 (four floors)
Exterior wall area (includes glazing area)	2524 m^2
Roof area	1074 m^2
window area	635 m^2 (25% of total wall area)
Wall U-value	0.47 W/(m^2.K)
Roof U-value	0.32 W/(m^2.k)
Glass Type	Double glazed clear glass
Lighting levels	Fluorescent lights, 20 W/m^2
People	130 per floor per building maximum (equivalent to 9.3 m^2/person)
Fresh air rate	20 CFM/person
Equipment	21.5 W/m^2
Air conditioning system	Two air-cooled chillers

Case study building description

The office building is a simple rectangular shape with dimensions of 76m long, 14m wide and 14m high. The base case shown in Table 1 was for the east-west orientation and comprised of IGU glazing area ratio of 25% with the glazing distributed equally on each of the longer faces of the building. The same parameters were specified for the north-south orientation but with IGU area ratio of 35%. The geographical location of the building site was 29.3°N latitude and 48°E longitude and °0 altitudes. Two orientations were selected for the building depending on the direction of the longer surfaces of the building. One was East-West while the other was North-South. More details of the building are given in Table 1. The constructions are typical of the building practice used in Kuwait with the U-values for the walls and roof (given in Table 1) are well within the minimum stipulated in the code of practice for energy conservation in buildings [4], which is 0.57 W/(m^2.K) and 0.4 W/(m^2.K) for walls and roofs respectively.

Glazing details

ASHRAE recommends extracting the optical properties of the glazing used from the National Fenestration Research Councils (NFRC's) spectral data disk [8]. This was done using the WINDOW computer program by arbitrarily choosing standard double clear glass and a film with spectrally selective properties for the clear laminated glass. The resulting optical properties and thermal characteristics of the glazing are listed in Tables 2 and 3. In Table 2, the data in the fourth column was obtained by calculating the ratio of visible transmittance (T_v) to the solar-heat-gain coefficient (SHGC). This ratio was included because of its physical importance since it implies that the higher the ratio the better the general performance of the glass in terms of daylight utilization and solar heat gain minimization. Glass manufacturers nowadays are aiming for ratios of higher than 2. It is important to note that the other data like building location, hourly climate data, construction materials, and casual gains, were the same for all cases apart from the IGU glazing area and the façade configuration (i.e. single or dual skin).

The relevance of Table 3 lies in its importance in allowing a detailed transient energy simulation to be conducted. For the double clear glass, coefficients for the solar transmittance, SHGC and absorptance for the outer external-facing glass (surface 1) and inner room-facing glass (surface 2) were obtained from the WINDOW computer program for the incidence angles listed in the table. The ESP-r program treats windows as transparent, multilayered surfaces and, therefore, accounts for all parameters that may influence the

Table 2

Properties of Glazing Types Considered in the Analysis (glass thickness assumed is 6mm)

Glazing Type	Visual Transmittance T_v	Solar Heat Gain Coefficient SHGC	Light to Solar Gain Ratio	Overall U-value W/m^{2}C
Clear Laminated	0.70	0.45	1.55	5.86
Clear double with 12mm air gap	0.78	0.69	1.13	3.16

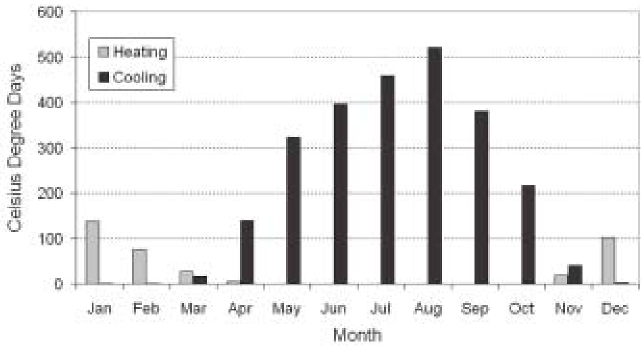
Table 3

Optical Properties at Different Incidence Angles.

Glazing Type	Property	Incidence Angles				
		0°	40°	55°	70°	80°
Clear Laminated	Transmittance	0.32	0.309	0.296	0.261	0.174
	SHGC	0.449	0.44	0.426	0.381	0.271
	Absorptivity	0.49	0.499	0.493	0.461	0.378
	Transmittance	0.569	0.535	0.472	0.324	0.139
Clear double glazed	SHGC	0.676	0.65	0.589	0.433	0.222
	Absorptivity (1)	0.19	0.208	0.225	0.244	0.239
	Absorptivity (2)	0.136	0.144	0.144	0.126	0.084

Fig. 1

Climate severity in terms of degree days for Kuwait's coastal zone [10].



amount of heat gained through them. Such parameters include heat absorbed in the glass, heat reflected, radiation penetration, conduction, long-wave radiation exchange with other surfaces and heat convection to the zone. In addition, since the sun's position in the sky is a function of the day under consideration, then the angle of incidence of solar radiation relative to a surface will change accordingly. For this reason, the optical properties in Table 3 were given as a function of the angle of incidence of solar radiation. Unlike the conventional way of calculating heat gain from glazing by way of using the heat transfer coefficient and SHGC at normal incidence, utilizing the detailed data in Table 3 ensured an accurate representation of the heat transferred through the glazing. ESP-r requires the optical properties of glazing to be available for five different incidence angles, as shown.

Imposed Simulation Parameters

A number of essential input data must be defined in order to be able to simulate the building under typical Kuwaiti conditions. Such input includes the building geometry, construction details, hourly climate data used, the ground monthly temperatures, casual gains, control strategy and operational schedule of the building. This information was defined for a typical governmental office building with the occupancy period for the weekdays from 7:00 to 14:00 hours. Accordingly, both sensible and latent heat for which ASHRAE [9] recommends values of 75 and 55 W/person were specified. It was assumed that the weekend (Thursday and Friday) was a non-occupancy period. With respect to the weekday control strategy, cooling temperature was set at 24°C and heating temperature was set at 22°C with 50% relative humidity. While for the weekend, cooling temperature was set at 26°C and heating temperature was set at 20°C with 50% relative humidity.

Figure 1 shows the severity of the climate in Kuwait in terms of degree days. The results were based on a heating base-temperature of 18°C and a cooling base-temperature of 21°C. The dry-bulb temperature was extracted from a typical meteorological year (TMY) of climate data in a coastal region. The data consisted of the dry-bulb temperature, diffuse radiation, direct normal radiation, wind speed, wind direction and relative humidity. The ESP-r uses this set of hourly data, and for sub-hourly simulation, it interpolates the data assuming linear correlations. The TMY was established from hourly weather files [10], which were collected continuously using the current setup for the Kuwait Institute for Scientific Research's (KISR's) weather station. The geographical location of the weather station was assumed to be similar to that of the office building. The longitude and latitude for this location were 48°E and 29.3°N respectively. The figure clearly shows that the cooling season is predominant in eight months of the year and has the highest annual peak. For this reason the peak electric load for cooling was chosen to be the parameter to base the glazing area limits on. In addition, during the cooling season, the sky is clear most of the time, which implies that the effect of solar radiation on the building's cooling load could be significant.

Modeling of air flow within the gap

The external outer skin or shield is fixed about one meter away from the building envelope. Due to buoyancy effects, air flow is generated in the gap and by keeping the lower and upper part of the outer skin open, the hotter air within the gap will escape through the top section of the outer skin openings and thereby encouraging cooler air to enter the gap from the bottom. This configuration ensures minimum heat build up within the gap particularly in the summer season. To account for this process, an air flow network was established in the computer building models with dual skin facades. During the simulation process of the ESP-r, the air flow balance calculation is coupled with the energy balance calculations per time-step to establish the resulting thermal and electrical load within the space of the building.

Results and Discussion

The whole simulation process involved conducting an annual hourly analysis of the energy consumption and peak loads requirements. For the peak load, only the cooling load was looked at since cooling is more of an issue for Kuwait mainly due to the long hot summer season. For the set objective for this study, a number of different scenarios were identified as described by Table 4. These cases were found adequate to determine the maximum glazing areas for the clear IGU considered. The method adopted to determine the maximum glazing area was based on the value of the peak electric power requirement for air-conditioning in terms of Watt per meter square area of living floor area. The reason for this lies in the fact that for office buildings, a limit of 70 W/m^2 is allowed by the code of practice for energy conservation in buildings. Therefore the analysis was aimed at finding out the glazing area for the IGU that will result in a peak cooling power requirement not exceeding the 70 W/m^2 limit. In addition, the calculation of the peak cooling power requirement for the air-conditioning was based on the assumption that the indoor environment of the building was controlled by an air-cooled chiller with a total system power rating of 2.0 kW per refrigeration ton (RT).

Default cases 1 and 2 resulted in a peak electric cooling load for the A/C that meets the code limit of 70 W/m^2. For this reason they were referred to for comparison with the other cases. The results of the simulations for the cases considered above are shown graphically in Figures 2, 3 and 4. Figure 2 shows

Description	IGU Area Ratio Percentage (%)
Case 1: Base case for building with no outer skin, East and West glazing orientation	25
Case 2: Base case for building with no outer skin, North and South glazing orientation	35
Case 3: Building with no outer skin, East and West glazing orientation	84
Case 4: Building with no outer skin, North and South glazing orientation	84
Case 5: Building with laminated outer skin, East and West glazing orientation	84
Case 6: Building with laminated outer skin, North and South glazing orientation	84
Case 7: Building with laminated outer skin, East and West glazing orientation	60
Case 8: Building with laminated outer skin, North and South glazing orientation	60
Case 9: Building with laminated outer skin, East and West glazing orientation	50

Table 4

Description of the Cases Considered in the Analysis.

Fig 2

Percentage increase/ decrease over the base cases for absorbed solar radiation.

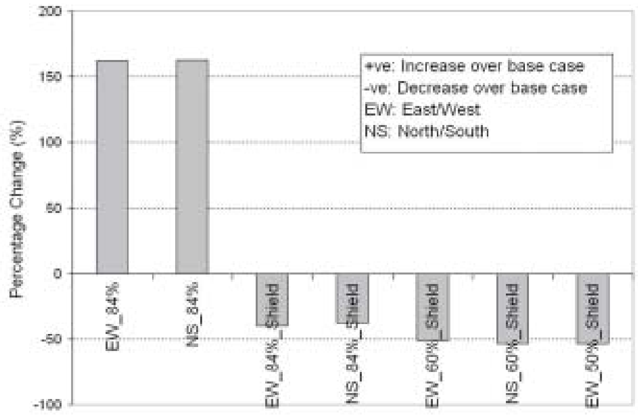


Fig 3

Percentage increase/ decrease over the base cases for annual electrical energy consumption.

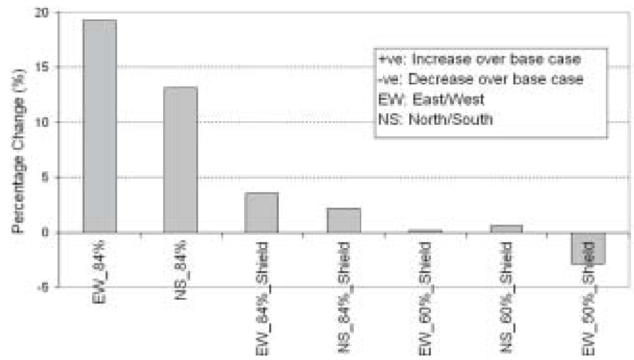
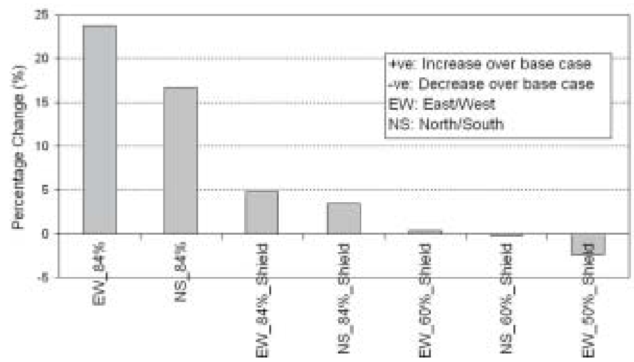


Fig 4

Percentage increase/ decrease over the base cases for A/C peak cooling electrical demand.



the effect of the outer skin shield on the amount of solar radiation entering the building space at the cooling peak hour. A comparison between the base cases and cases 3 and 4 indicate that the increase in the IGU area resulted in an increase in the absorbed solar radiation of 162% and 163% for the east-west and north-south orientations respectively. Whereas the cases with the laminated shield (i.e. cases 5 to 9) the reduction in the absorbed solar radiation over the respective base cases ranged from 38% to 53%. It should be noted here that the benefit of the outer skin can also be gained for opaque walls as lower solar radiation levels will be absorbed by the walls which results in lower heat gain through the wall construction.

Figure 3 shows the percentage change in the annual electrical energy over the base cases. It can be seen that for the east-west case with 60% ratio of IGU (case 7) the increase in the annual energy consumption is almost negligible at 0.14%. While in the case with only 50% area ratio of IGU (case 9) a reduction of about 3% was observed. Cases 5 and 6 with 84% area ratio of IGU resulted in an increase in annual energy consumption of 3.6% and 2.1% for the east-west and north-south orientations respectively.

With regards to the code of practice for energy conservation, Figure 4 is the most important as it clearly indicates whether the resulting air-conditioning electrical load for cooling is within the limit stipulated in the code for office buildings. It can be clearly seen that cases 7, 8 and 9 meet the code limit requirement with additional saving resulting from case 9 (east-west orientation with 50% area ratio of IGU).

Conclusions

The addition of the clear laminated outer skin resulted in significant reductions in the amount of solar radiation entering the building. This reduction has an impact on both the peak cooling load requirements and annual energy consumption. Such application warrants the use of larger areas of standard clear IGU which has a desirable benefit of providing a comfortable working environment within the office building in terms of both thermal and visual comfort at the same time providing high neutrality to the exterior appearance of the building.

It was found that in the presence of the outer skin, the maximum glazing area for clear IGU was 60% for both north-south and east-west orientations. For the east-west orientation this is an increase of more than 100% in the IGU area ratio compared to the base case with no outer skin. With this IGU ratio, the resulting peak electric cooling for the A/C is within the code limit of 70 W/m^2. In addition, the annual energy consumption for the cases with 60% area ratio of IGU and the outer skin was found to be almost the same as that for the base cases (i.e. with smaller glazing areas and without the outer skin).

In the analysis presented in this paper, the effect of day lighting on energy consumption was not considered. Moreover, the air flow induced within the gap between the building envelope and the outer glass skin was not utilized for ventilation within the building space. During the heating season, this hotter air can be used in heat recovery units to warm up cooler fresh air thereby reducing the heating load on the HVAC. These two issues can be considered in future work together with a detailed cost benefit analysis to arrive at a configuration that is suitable for the local conditions.

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