Feasibilities of Using Energy–Efficient Glass Walls in Air Conditioned Buildings in Kuwait

Yousuf Alhendal, Aboelyazied M. Kuliab, Rafik M. El Shiaty

Abstract— This paper describes methods of improving glass walls thermal resistance in air conditioned buildings. It is investigated the effect of glass wall thermal resistance on the indoor temperature of different rooms in the air-conditioned of buildings. Design and construction of glass walls have significant effects on building comfort and energy consumption. The effect of solar radiation on air conditioned building thermal load estimation is very high due to glass solar radiation and conductivity. The solar radiation heat gain through building based on the shape and glass specifications. The glass walls thermal resistance of wall is increased when using clear surface, low thickness, and large area. So, the surface area direction and specifications of glass walls; as one of envelope which has an important factor. Heat gains through various types of glass walls were studied. Optimization and testing of different types of glass strips or layers were carried out theoretically and experimentally as well. A series of experiments on different types of glass with special strips were performed. Different techniques of glass film covering were tested experimentally with simulator of building. The results show that glass type K70 or K80 can be used to decrease the heat loss from air conditioned building more than 40% in very hot days.

Index Terms— Glass wall; Solar radiation; Energy saving; Air conditioned buildings.

I. INTRODUCTION

In the most commercial buildings, large glass areas are install on the external walls to give an even distribution of light. Also, it was used in the case of large open-plan building offices to give people proper view and a sense of contact with the external world. In the air conditioned buildings, the large window areas have created problems on the thermal load estimation. Generally, using a large intense glass external wall lead to a lot of sunlight enters to building which causes overheating in it. Using extensive glass walls in air-conditioned buildings construction such as doors and windows, or external faces increases the thermal load in the buildings. In some application it can use a physical barrier between exterior and interior without obstructing visibility which lead to decrease the storage heat in the buildings.

In the most application of air conditioned buildings especially in Kuwait, ordinary glass is completely transparent to solar radiation extending from the different rays. The spectrum of solar radiation received at the earth's surface which can be enters to building through outer glass walls. It is known that the distribution of solar radiation stored energy is based partly on the height of the sun, the moisture concentration and the amount of dust in the atmosphere. Due

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to half or more of all solar radiation is infra-red, it is lying outside the visible range, [1-4]. In the case of air conditioned building, there a lot of heat gains sources such as conduction through external walls, glass, direct solar radiation, ventilation, people load, equipments, lights, etc. estimating those individual thermal loads and then adding them up will give the total thermal load in the building. Whereas these loads can be divided in to two main heat types total sensible and latent loads. The total cooling load in the buildings based on the different factors such as glass type, glass surface area, wall insulations, ventilation rate building type etc. It can be using laws of thermodynamic and heat transfer to estimate cooling load in the buildings. Step by step calculation procedure was listed in the literature [5].

The overall heat transfer coefficients for all the components of building gall walls are computed with the help of thermal properties of the glass material. For the design outside & inside conditions and the building materials used, cooling load temperature difference, solar heat gain factors and cooling load factors are calculated [6]. The low thermal resistance glass wall can be obtained by adding extremely thin special film layers as metallic oxide to normal glass. These layers will lead to increase the shading effect on the clear glass especially in very hot climate such as in Kuwait. The rate of heat gain by solar radiation in most office building is reached 15-20% from total heat gain in buildings [7]. Using these outer layers on clear glass will lead to increase the thermal resistance and decrease the rate of solar radiation enterer across glass wall areas.

Also, it is known that the best location for glass wall and windows in the buildings based on the area where as building was installed. The best direction used for installing glass walls in the building in Kuwait is north and south due to allow lower level and better shaded most of the day. Using low thermal resistance of glass wall leads to increase the rate of heat loss by conduction or increase the rate of transfer through building by solar radiation. Because the dry bulb temperature is very high in Kuwait through the summer seasons, so the window glass should be designed to give protection from direct sunlight and it must conform to various requirements of light transmission. However, in case of huge area buildings and offices with floor-to-ceiling glazing, the use of normal double-glazing with 80 % light transmission has poor point. Also, the window area would be very bright with comparison by using artificially lighted area in the rooms as listed in MEW Code of Kuwait.

On the continent, in most applications in Kuwait, the glass windows with a 30 to 40 % transparency are used. To prevent heat loss from air-conditioned especially at very hot days in summer. It should be used lower transparency in range of 10 to 20 %, [9]. So, his paper directly investigates the methods of improving wall glass thermal resistance in air conditioned buildings in Kuwait weather conditions. The study was

carried out analytically and experimentally. Different types of efficient glass types were studied with using building simulator.

II. GLASS COATING FILMS TECHNIQUES

To improve the thermal resistance of glass walls, it can use directly special flexible layers which are called sun insulation. The specifications of sun insulation materials used with glass walls based on the material used, thickness, ambient condition, temperature difference between outer and inner surface, and temperature daily range applied. Generally, the effective sun-insulating glass layers with different light transmission can be produced by using single gold deposit material. With compared with the sensitivity to the light of the human eye, the light transmission is 40% and total energy transmission 26 %, [9].

In case of air conditioned vehicles such as cars, trains, planes the applying gold film layers is very effective for decreasing heat gain through it. To reduce the effect of direct sun rays on the glass walls of air conditioned buildings is changing the optical properties of the gold film in such a way as to retain high heat-reflectivity transmission through glass surfaces. The techniques applied are related to the well known process of reducing the reflectivity of glass wall surfaces which are used in photographic apparatus and the blooming of instrument lenses. By using very thin dielectric films with a proper refractive index and thickness, the reflected light rays at the surface of this additional film can be obtained with similar amplitudes approximately.

On the other hand, the manufacturing of sun insulation layers films with very high reflectivity with long wavelengths can be caused by the high electrical conductivity of the metal. Theses layers should be very isolated, homogeneous and continuous. Using the techniques of firing on to the glass wall surface can not produce continuous glass cover films. But using technique of vacuum-sputtered coatings of glass sun-insulation material with a 30 to 40 % transparency will lead to produce very low surface resistances of a few ohms per square meter. A recent application is applied in the case of very large glass walls and in cars is combining gold films with interference layers for sun-insulating glass.

In the case of large glass walls is governed by the greater heat loss from buildings caused by the higher light transmission occurred by solar radiation in the visible range. The additional glass film layer effect is significant on heat loss from air-conditioned building. Using the anti reflection glass film effect of the interference layers; instead, which have blue appearance which lead to increase the rate of glass wall shading. In recent years, currently, the sun-insulating glass wall materials was developed as a color palette to give architects more scope in designing the office air conditioned buildings. The plate glass wall with different shadow effect for the blue, gold, or bronze, when it saw from the outside, is available in market and can be applied. In most these commercial types of gold film is considered as selective filter element. Generally, combination of the gold film with interference layers and alloy layers can produce various colors with proper thicknesses, [1].

Also, the using of double-glazing which is treated with a gold coating film is better solution for decreasing energy loss from air conditioned buildings, especially the part from that of protection from solar radiation. Whereas, the heat transfer rate is much lower than that of normal double-glazing. This means that in summer, with very high outdoor temperatures, cooling energy can be reduced by about 40-50 % approximately, [1]. Figure 1 shows the performance of preferred sun-insulated film layer which can used in the control the sun radiation across glass walls of air conditioned buildings. The main aim from using this type of glass is reflecting a big part from sun light to outside without a big effect of the visible light through building outside rooms. The reflection a big part from sun rays of direct solar radiation will lead to decrease the thermal heat gained to the building across the glass wall surfaces, and then the cooling load in the building will be decreased which lead to decrease the energy consumption by air conditioning (A/C) systems. Whereas, in this range of wave lengths of these transparent gold films, the reflectivity is very high.
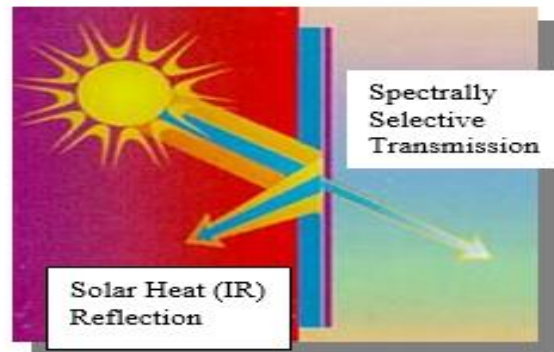

Figure 1: Preferred Sun-insulated film

Figure 2 shows a typical spectral reflectivity of a gold interference coating on the one side of the glass exposed to the atmosphere. In the range of visible part, the reflectivity is very low although the effect of the interference layer was included. Also, the glass layer transmission is very high as applying of insulating glass pane 66 %). However, in the zone near to the infra-red range, the reflectivity was increased sharply and reached more than 96 % in rang of wave length of the 4 μm. This corresponds emissivity of glass is 0.04 compared with 0.84 for non-layered window glass, [1].

On the other hand, applying the heat-reflecting film on the inner surface of the glass wall is also can be used in casing of warming building of houses in very cold day of winter season. But this application is not effective in Kuwait because the winter is warm not very cold and also will affect on the visible region through building rooms. The performance of this type of sun-insulating glass is best shown by an energy saving. This shows how much of the effective total solar radiation is directly reflected (solar reflection) and how much is transmitted (solar transmission).
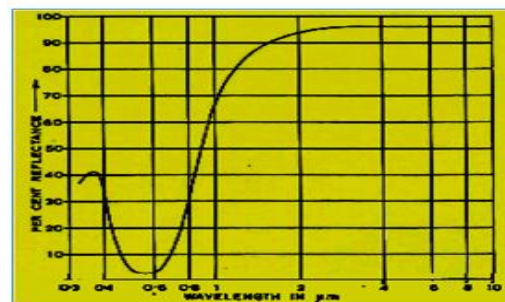

Figure 2 shows an example of the spectral reflectivity of gold interface coating system on the side of the glass (Rolf G. 2007) [1]

Using sun-reflected layer with special coating reduces the heat transfer through the two plate of double glass window due to increase of thermal resistance of glass wall. It can using air space between two glasses of window which lead to decrease heat loss from air- conditioned building. For normal double glazing, the heat loss is reached 2.6 kcal/m²h°C but installing an air space of 12 mm, the heat loss is reduced to 1.5 kcal/m²h°C. so, the using glass wall film layers will give degree of heat insulation equivalent to that given by a 30 cm thick wall of polished brick or tiles approximately [10].

Helena 2002, [11] investigated the effect of window glazing on the building energy consumption during heating or cooling processes. It is shown that the window glass specifications such as type, color, thickness, played big effect on the energy efficiency of building. The results showed that as the energy-efficiency of buildings increase, if the *U*-coefficient of window decreased. In order to decrease the annual cooling load in very hot days, the overall heat transfer coefficient of glass window or glass area must be very low. The investigation showed that for a building with a window glass area to total wall surface area ratio of 15 % and insulated according the current Kuwait building code, the *U*-values should thus on average be lower than 1.0 W/m²K which applied in case of clear glass.

Peter et al., (2013)[12] studied directly the methods of reducing convective heat transfer through windows with installing blinds and curtains. The reducing of air gaps around the curtain and pelmet of window will improve performance of building energy consumption and A/C system comfortable. So, selecting energy efficient windows lead to reduce the peak heating and cooling load, which can reduce the size of an air conditioning system by 30%. Also, Solar shading devices is another energy-efficient technology, which is used together with windows. With a good solar shading system, cooling demands can be reduced dramatically (up to 80 %), Dubois (2001)[13].

III.   EXPERIMENTAL SET UP

A series of experiments on different types of efficient glass was tested in the simulation heating system. Different temperatures were measured on the system. Figure 3 shows the experimental set up system used in the test the glass types. As shown the test rig was consisted of an insulated metal box from all faces, the dimensions of box is 60 cm x 60 cm x 60 cm. The box was prepared by hall from one side to install the glass test part (specimen). The test rig consists of heating source to simulate different ambient temperature in the room. Different temperatures were measured with using low temperature copper/constantan thermocouples. The five measured temperatures as the following: inner room temperature (Ti), surface inner glass (Tgi), surface outer glass (Tgo), outer room temperature (To) and the ambient temperature (To). It was using digital temperature indicator to read the temperature. Figure 3 shows practical test rig used in study. The unit consists of building simulator box with different measuring instrumentation devices such as temperature, solar intensity, etc.

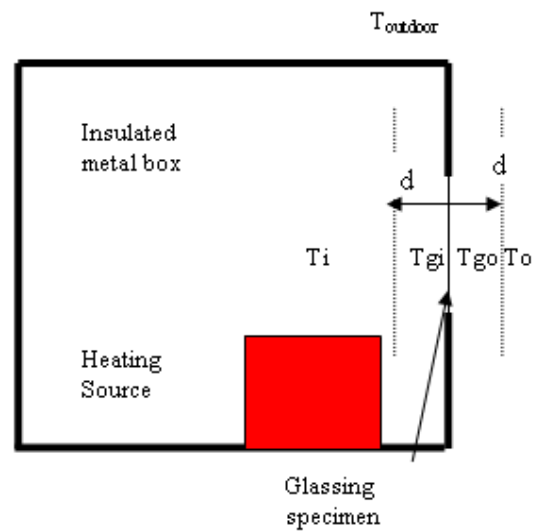Figure 3 shows test rig unit used in the study

Figure 4 shows the flow chart of test rig unit used in the study.

Figure 5 shows HOBO Micro Station Data Logge (also known as Pyranometer)

The readings were recorded for 2 hrs for different types of glasses. Multi-point selection switch was used to select different temperatures. The power consumption for heating the space was measured directly with using wattmeter instrument. It was use digital indicator and selection switch to shows the temperature at each section and layer of space simulator. It was used a HOBO's (shown in Fig. 5), Smart Sensors, for measuring solar radiation in and out the box (test rig). This Micro Station Data Logger can make up to 500,000

measurements of solar radiation in W/m². Launched from a computer, it can be placed on windows or in the open to read the solar radiation transmitted. This sensor is very considered proper sensitive for measuring small values of solar radiation in small test rig. The solar radiation distribution through glass window or wall is shown in the Fig. 6.
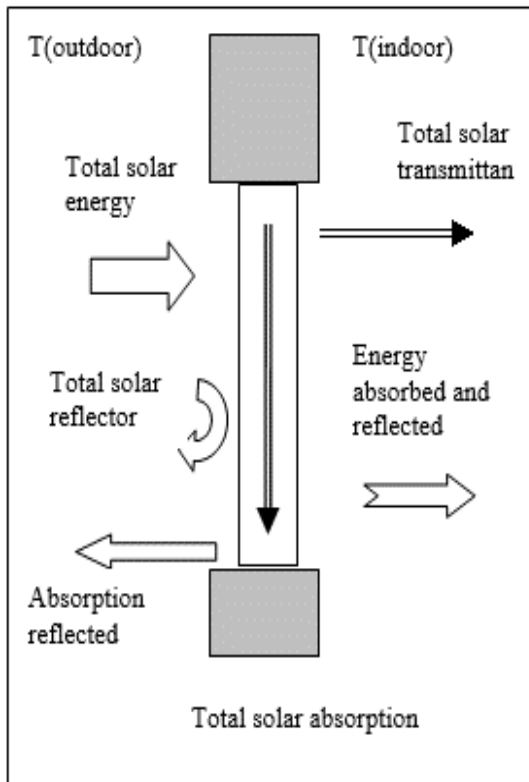

Figure 6 shows flow chart of solar heat through glass windows

It was used to measure solar radiation through different types of commercial efficient glass which test in the glass. In very hot climates, the solar radiation takes a big part from the cooling load through buildings. The solar heat gain through glazing system can be simulated as following flow chart given in the shown in Fig. 7.

The measuring solar intensity is very important to analysis the effect of solar radiation during the calculation of solar effect on space used in the study. Whereas, the solar heat gain in the building related by solar heat gain factor.

The different solar heat gains were estimated experimentally for most types of glasses. Figure 7 shows data determined for solar radiation heat gains rations in glass of K-80 (4mm). These values were compared with 4 mm normal clear glass. It was shown that the total solar heat reduced reached 45%. The efficiency of glass is 1.37, the shading coefficient was reached 0.45, the U-factor for this glass is 0.94 W/m²K. so this type of efficient glass can reduce solar energy transmitted to building with 45%. The overall heat transfer coefficient affect directly on the heat conduction through glass wall window. Increasing the U-factor of glass lead to increase the heat gain through building, and then energy consumption of A/C building will be increased also. So, it is better to select low overall heat transfer coefficient for glass wall used in very hot climate as case of Kuwait.
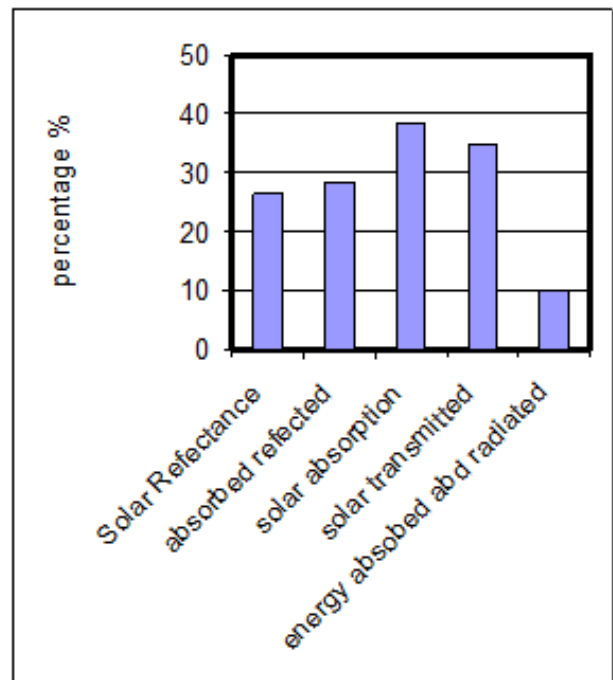

Figure 7 shows the Percentage Solar Radiation through Film Coating using Glass K-70 type

IV. MAIN GOVERNING EQUATIONS

The procedure of the estimation the air-conditioned thermal load based on the finding the inside surface temperatures of the building structures that enclose the conditioned space due to heat balance at time t and calculating the sum of the heats transferred from these surfaces as well as from the occupants, lights, appliances, and equipments at given time t. also, the heat loss by outside duct can be taken in account. Ventilation rate for indoor air quality should be taken in consideration.

The inside surface temperature of each surface $T_{i,t}$, in °C, can be determined from the following simultaneous heat balance equations:

$$q_{i,t} = \left[h_{ci}(T_{r,t} - T_{i,t}) + \sum_{j=1}^{m} g_{ij}(T_{j,t} - T_{i,t}) \right] A_i$$
$$+ S_{i,t} + L_{i,t} + P_{i,t} + E_{i,t} \qquad (1)$$

Where
  h_{ci}: convective heat transfer coefficient, kW/m².°K
  g_{ij}: radioactive heat transfer factor between inside
      surface i and inside surface j,
  $T_{r,t}$: space air temperature at time t, °C
  $T_{i,t}$, and $T_{j,t}$: average temperature of inside surfaces i
  and j at time t, °F
  A_i: area of inside surface i, m²
  $S_{i,t}$, $L_{i,t}$, $P_{i,t}$, and $E_{i,t}$: solar radiation transmitted through
    windows and radiative heat from lights, occupants, and
    equipment absorbed by inside surface i at time t, kW

In the previous Equation (1), $q_{i,t}$, in kW, is the conductive heat that comes to surface i at time t because of the temperature excitation on the outer opposite surface of i. This conductive heat can be found by solving the partial differential equations

or by numerical solutions. The number of inside surfaces i is usually equal to 6, and surface i is different from j so that radiative exchange can proceed.

Radiant energy from the sun spaces transparent materials such as glass becomes a heat gain to the room. Its value varies with time, orientation, shading, and storage effect. The solar heat gain can be found from the following equation:

$$Q = SHGF \times A \times SC \times CLF \qquad (2)$$

Where

> Q: solar radiation cooling load for glass, kW
> SHGF: maximum solar heat gain factor, kW/m^2
> A: area of glass, m^2.
> SC: shading coefficient
> CLF: cooling load factor for glass.

Actually, the maximum solar heat gain factor (SHGF) is the maximum solar heat gain through single clear glass at a given month, orientation, and latitude. The values for the SHGF based on the site of building and the direct solar radiation – when the sun shines on the glass. External shading from building projections may shade all or part of the glass. The SHGF values for any shaded glass are the same as the N (north) side of the building, which also receives only indirect radiation.

The heat gain through partition wall that flows from interior unconditioned spaces to the conditioned space through glass walls can be estimated from Eq. (3):

$$Q = U \times A \times \Delta T \qquad (3)$$

Where

> Q: heat gain by glass, kW.
> U: overall heat transfer coefficient for glass, kW/m^{2}K.
> A: area of structure, m^2.
> ΔT: temperature difference between two sides of glass, ^{o}C

The glass overall heat transfer coefficient (U) depends on the thickness, and the thermal conductivity of glass coating materials layers. The U-factor can be calculated from:

$$U = \frac{1}{\dfrac{1}{h_i} + \dfrac{L}{K} + \dfrac{1}{h_o}} = \frac{1}{R} \qquad (4)$$

Where h_i and h_o are indoor and outdoor heat transfer coefficients, k glass conductivity, and R is the thermal resistance of window glass.

The energy saving ratio can be calculated with using the following simple Eq. 5:

$$\Delta E = \sum \left[0.001.(SGHF.\Delta SC + \Delta U.\Delta T.t).S \right] \qquad (5)$$

Where: ΔE is reduction of solar heat admission, SHGF is local solar radiation value, ΔU is difference in U factor, ΔT is the temperature difference, daily solar time, and S is glass

area at each orientation. The factor solar heating gain factor (SHGF) is based on the different factors such as building orientation, site altitude angles, solar intensity, building design, etc.

V. RESULTS & DISCUSSION

A series of experiments were carried out on the different commercial glass types in market of Kuwait. The measurement depended on the fixing indoor temperature at 21°C. The sample of results was shown in the following figures. The results were compared with 4 mm clear glass. With ballast factor, (Bf = 1). In the simulated test rig the time was neglected because it used heating source instead of sun. Also it was assumed that every kilowatt, (kW) reduction of solar heat gain can save 1 kW of cooling consumed electricity.

A normal double glazing unit with the usual 12 mm air space has a heat loss of 2.6 kcal/m^{2}h^{o}C compared with 5 kcal/m^2 h^{o}C for single glazing. This improvement is due to the additional heat insulation of the enclosed air space. Heat transfer between the colder outer pane and the inner pane is due firstly to the thermal conductivity of the air space with additional convection and secondly to the radiation exchange between the two panes of glass. The radiation exchange with an air gap of 12 mm is about double that of the figure of thermal conductivity and convection.

The experimental data was analyzed and shown in the Figures 8 to Figures 8 to 12. a lot of date was taken during the measurements, only steady state condition is considered and taken. Other singular measurements were cancelled. Figure 8 shows the effect of using some types of commercial glasses on the energy consumption of building.
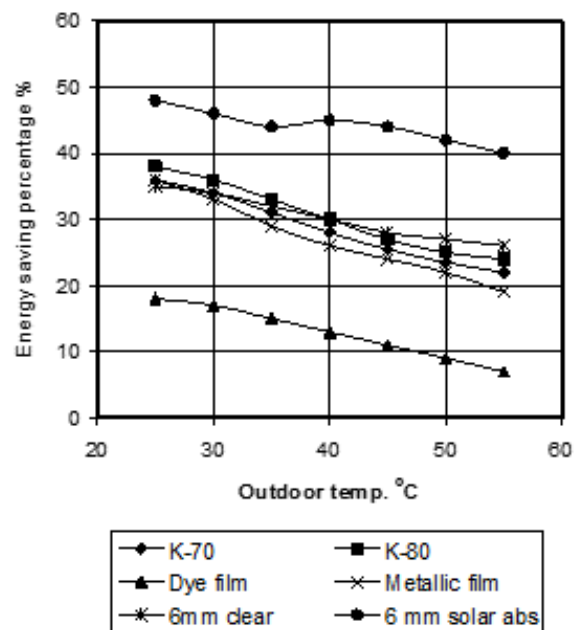

Figure 8 : shows the Energy saving percentages for different commercial glasses

Glass type 6 mm solar abs is the best type, whereas the energy saving ration is the highest with comparison with other types. The average energy saving ration is reached 45% in this type.

Also the effect of increasing ambient temperature on this types of glass is low.
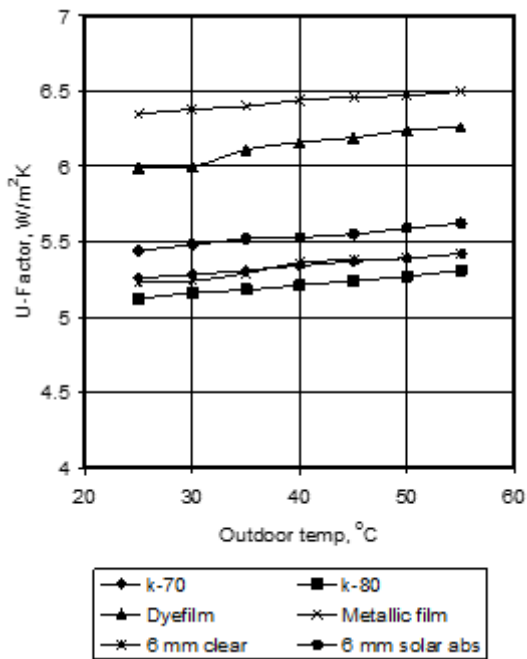

Figure 9 shows the overall heat transfer coefficients with outdoor temperatures for different efficient of glasses

For effective lighting through a sun-insulating glass, a high degree of opacity will be required in this area of infra-red radiation. Attenuation of infrared radiation must take place mainly by reflection and not by absorption, as the absorption of solar radiation leads to heating of the glass, which at a high temperature will transfer a considerable amount of the absorbed solar radiation into the room by convection and long-wave secondary radiation. Then there is the secondary heat emission of the glass by convection and long-wave temperature radiation outwards and inwards, depending on the rise in temperature of the glass produced by the amount of solar radiation absorbed.
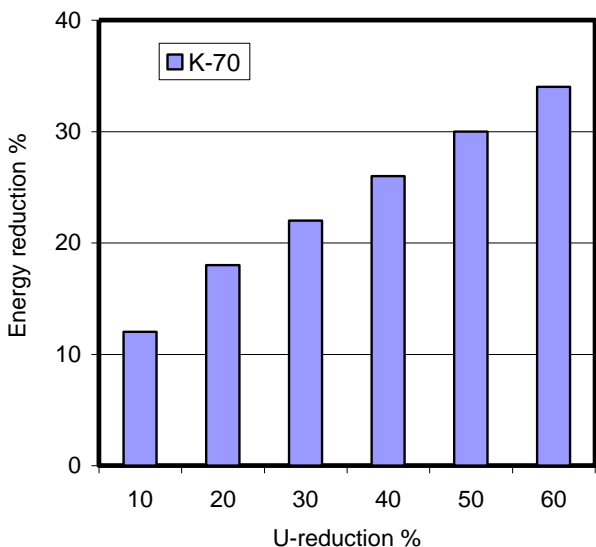

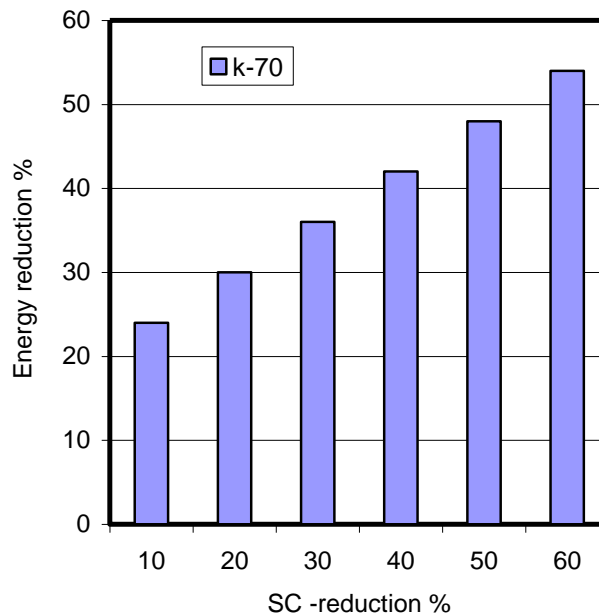Figure. 10 shows energy reduction rate with U-reduction percentage for glass K-70.

Figure 11 shows the effect of decreasing shading coefficient of the energy reduction.

The glass window efficiency is defined as the ratio of visible light to the total transmitted solar energy, so:

$$\eta_G = Tvit / SC$$

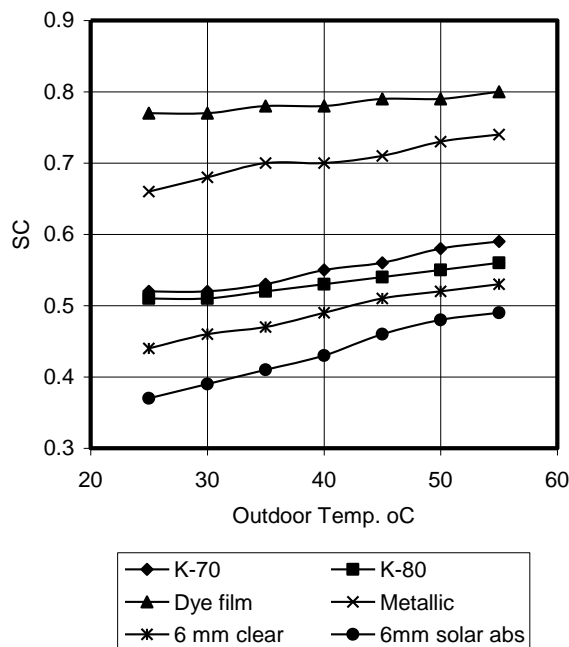where, Tvit is the visible light, and SC is shading coefficient.

Figure 12. shows the shading coefficient (SC) with outdoor temperatures for different types og glasses.

The total amount of heat reaching the interior of the room (total energy transmission) is therefore the sum of the solar transmission and the secondary emission into the room. Obviously the transparency of the glass (in relation to the

sensitivity to light of the human eye) is also important. It is usual to give both figures in the form of a coefficient, transparency1 energy transmission. The figures shown in the energy diagram of Figure 2 relate to double-glazing with semi-transparent gold applied to a single glass pane.

The interference layers increase transmission in the visible range considerably. Transmission is increased from 40-60% which is only 15% less than that of a clear glass double-glazing unit (80% per cent). In the infra-red range, on the other hand, the reflectivity of the gold film is largely retained. That the reflectivity values differ somewhat for wavelengths of about 2pm for which the effect of the interference layering is almost nil is due to the fact that the thickness of the gold films is somewhat different in these products. By its very nature, the total energy transmission, 45% of the type with the interference layer, is higher than in the type with the single gold film.

VI. CONCLUSION

Windows typically occupy about 15 to 20 percent of the surface area of the walls. Windows not only add aesthetic looks and often a very important aspect of building, but also a very significant component of building heating and cooling costs. Windows lose more heat per square foot of area in winter and gain more heat in summer than any other surface in the building. So, towards energy saving glazing in hot climate, it should be select glazing of lower shading coefficient, lower U-factor, higher visible light transmission, higher efficiency and lower visible light reflectance. The results showed that the applying special glazing films on its windows would significantly reduce the solar radiation which enters the buildings, and therefore, lower the heat gain due solar radiation through buildings. Then the power consumption by air-conditioning system is reduced directly. When using better glassing, this lead to more energy efficiency in air conditioned buildings. The glass type K70 or K80 can be used to decrease the heat loss from air conditioned building more than 40% in very hot days.

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