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COST EFFECTIVENESS FOR SOLAR CONTROL FILM FOR RESIDENTIAL APPLICATIONS

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ABSTRACT

For the existing housing, retrofitting single or double glazed clear glass window with solar films can be an effective measure to reduce their peak power demand, and large scale application of the same on national level can be an effective tool for demand side management. This paper analyses the field performance data of a solar control film, retrofitted in a Kuwait villa, for establishing its technical viability and cost effectiveness. The paper concludes that the solar film, besides enhancing the thermal comfort, reduced the peak cooling demand and the peak power demand by 6.7% and 4.7%, respectively, during the peak summer period.

Key words: Fenestration, peak power demand, solar glare.

INTRODUCTION

In Kuwait, fast economic growth and rapid urbanization over the past few decades has resulted in ever increasing demand for electricity, which is well over 5% annually, at present. During the past five years, the power demand grew from 6750 MW in 2001 to 8900 MW in 2006 and during the same period, the electricity consumption increased from 34300 GWh to 46400 GWh. The Ministry of Electricity and Water (MEW), the sole body responsible for meeting the national requirement of electricity and water, has to spend nearly KD200 million on yearly for the purchase of new power plants while its fuel bill for 2006 for electricity generation, estimated for a fuel price of KD10/bbl was KD730 million (MEW, 2007).

Buildings are the major consumer of electricity in Kuwait. Together, air-conditioning (AC), a must for all types of buildings, and lighting account for over 85% of peak power demand and nearly 60% of the annual electricity consumption (Marafie et al., 1989). Thus, implementation of energy conservation and energy efficiency measures in buildings, particularly for their AC and lighting systems can be very effective for demand side management.

In the modern buildings, fenestration is a major contributor to the building cooling load. Also, ability of the fenestration system to allow visible light can be very effective in limiting the use of artificial lighting (Al-Hadban and Maheshwari, 2008). Thus, electricity demand in buildings for AC and lighting can be effectively controlled by selecting an appropriate fenestration system. In Kuwait, fenestration quality in general and for the residential villas in particular is poor. Most of the villas use single glazed clear glass windows. Heat transfer through these windows is a major source of heat gain and contributor to the building cooling and peak power demand. Retrofitting these single or double glazed clear glass window with solar films can be an effective measure to reduce peak power demand in buildings and large scale application of the same on national level can be an effective tool for demand side management.

This paper based on field performance data establishes technical viability and cost effectiveness of retrofitting windows in Kuwaiti villas with solar control films. High quality solar control film of a reputable make was used to retrofit double glazed-clear glass windows in a newly constructed-unoccupied villa in Eghailah (Plate 1).

DESCRIPTION OF BUILDING, HVAC SYSTEM AND SOLAR CONTROL FILM

Description of Building and Air Conditioning System

The building used was newly constructed residential villa located south of Kuwait at Egailah residential area. The total land area of the villa is 480 m^2 . It consists of 3.5 floors; basement, ground floor, 1st floor and half second floor. It is constructed with reinforced concrete along with columns and beams encapsulated with thermally insulated bricks, and double glazed clear glass windows and doors with total glazing area of 50 m^2.

AC system of the building comprises packaged units and split units. Full details of AC system with connected load of 55.4 kW are given in Table 1

Solar Control Film

Solar control film was selected based on strong technical performance characteristics such as clear, neutral, non reflective visual quality that would restore the building to its original appearance, while reducing building cooling demand. IQue Anchor Product film with a commercial name 73FG (V-Cool

70) was used. It has a total solar heat rejection of 65%, a visible light transmission of 73% and shading coefficient of 0.5.

FIELD DATA COLLECTION ANALYSIS

Instrumentation and Field Data Collection

Technical specifications of instruments used to measure and record global solar radiation, indoor and outdoor temperature and humidity, and cooling production and power demand of the AC system are given in Table 2.

The internal lights during the experimentation were completely switched off, while the doors and the windows with their glazing surfaces were cleaned and kept fully closed. Also, efforts were made to have minimal movement. Global solar radiations were measured simultaneously for incidental and the transmitted radiation on the exterior and interior surfaces of the glazing. These measurement were carried out for few days for all the four orientations of the building. First data were collected for a period with a clear glass without any film to establish the baseline cooling and power demand hourly patterns. The same process for the similar duration was repeated after applying the solar film on the interior glazing. The cooling and the power demand for the baseline were compared after applying the solar control film of the product that has been selected. The reductions in hourly cooling and power demands were quantified. This information has been used to estimate the impact of reducing the peak power demand and the annual energy consumption.

Field data were collected during the last week of September and first week of October. Data for 16th September, without the solar control film and for 1st October, with solar control film are analyzed. Incidental and transmitted global solar radiations on the east and west windows for these two days are shown in Fig 1 and 2 respectively. Also, for these days, the measured profiles for the indoor temperature and relative humidity (RH), outdoor temperature, power demands of the A/C units, and the total for the villa were measured.

Field Data Analysis

Using the temperature and RH data, the enthalpy of the indoor and outdoor were established, and their difference, which represents the fresh air or ventilation load, was calculated. These values for the two days were very different as far as the ventilation load was concerned. Likewise the indoor-outdoor temperature differential, which manifests the transmission load for the two days, was very different. Accordingly, the days selected for the comparison had very different cooling load. Therefore, the values could not be used to predict the savings realized due to the application of the solar control film. Alternatively, reduction in transmitted radiation data has been used for estimation of reduction in cooling load and thereby a reduction in the power demand of the A/C units.

Reduction in Cooling Load

The reduction in the transmitted radiation (ΔIt) after the application of the film is assumed to be the reduction in cooling demand (Qc). This is based on the assumption that the transmitted radiation is fully absorbed by the interior of the villa and it contributes instantaneously to the cooling load. ΔIt is estimated as the difference of the transmitted radiation without the film (It) and the transmitted radiation with the film (Itwf) for the same incidental radiation (Ii).

$$\Delta It = It - Itwf \quad (1)$$

The readjusted transmitted radiation after the film for the 1st October (RItwf) was for the variation in the incidental radiation as follows:

$$RItwf = (Ii \text{ for 16th Sep}/ Ii \text{ for 1st Oct})* It \text{ for 1st Oct} \quad (2)$$

The hourly average values of the incident radiation, the transmitted radiation without the film and the transmitted readjusted radiation for the east and the west glazing are shown in Figs 3 and 4, respectively. The reduction in the transmittal radiation for the east ($E\Delta It$) and the west ($W\Delta It$) were calculated. Finally, combing these values with the glazing areas covered with the films for the east (EA) and the west (WA) glazing, reduction cooling demand for the villa (ΔQc) is estimated as follows For different hour of the day, the value ΔQc in RT is presented in Fig. 5.

$$\Delta Qc = EA * E\Delta It + WA * W\Delta It \quad (3)$$

Reduction in Power Load

Reduction in power demand of the A/C system (ΔPc) at a given time is estimated as follows, as the product of ΔQc and the power rating (PR) of the A/C units.

$$\Delta Pc = \Delta Qc * PR \quad (4)$$

The expected PR for the actual ambient temperature has been estimated assuming a 2.75% (ElSherbini and Maheshwari, 2010) improvement or reduction in PR for every degree Celsius drop in ambient temperature. For different hour of the day, the value ΔPc in kW is presented in Fig. 5.

Reductions in Cooling Demand and Power Demand for the Peak Summer Day

The reductions in the cooling demand and peak hour power demand for the ambient temperature of 40.4C were estimated at 1.3 RT and 1.8 kW, respectively. For the design dry bulb temperature of 46C, the reduction in the cooling demand (ΔQcD) and power demand (ΔPcD) are estimated as:

ΔQcD =1.3 x(46-24)/(40.4-24) = 1.74 RT (5)

ΔPcD = ΔQcD x 1.6 = 2. 8 kW (6)

Based on the installed capacity of A/C units of 25.8 RT, retrofitting of the building reduced the cooling demand by 6.7% and same is the reduction in the peak power demand for the AC. Considering that AC account for 70% of the peak load, the retrofitting is going to reduce the building peak power demand by 4.7%.

Reduction in Annual Energy Consumption

Reduction in annual energy consumption for the cooling season has been estimated by estimating the reduction in monthly heat gain in the building and the weighted average power rating of the A/C units for that month. As a first step, monthly irradiation on plane vertical surfaces for different orientations was estimated (Al-Taqi et-al, 2009). The results are shown in Fig. 6. Using the Eq. 3, the monthly reductions in heat gain have been estimated and the results are presented in Table 3. Using the monthly average ambient dry bulb temperature, the weighted average power rating of the A/C units were estimated. The cooling season has been considered from March to November. The annual energy savings were estimated to be 9763.9 kWh/y.

COST-BENEFIT ANALYSIS OF SOLAR CONTROL FILM

This involved establishing reductions in cooling demand and power demand by retrofitting all the windows with the solar control film and conducting the cost-benefit analysis using the cost data from the film dealer.

Combining the benefits such as reductions in cooling capacity ,power demand and annual energy consumption of retrofitting the glazing with solar films, with the cost of the film and other economic parameters specified in Table 4, a cost-benefit analysis has been conducted to estimate the pay back period of retrofitting the glazing with solar films. The pay back period (n) years has been estimated as follows:

n = net capital expenditure / Annual cost of saved electricity (9)

where

Net Capital Expenditure = Cost of the installed film - (Cost of reduced A/C capacity + Cost of reduced power) (10)

and

Annual Cost of Saved Electricity = Annual reduction in electricity consumption

(kWh) * unit cost of electricity (KD/kWh) (11)

Analysis has been carried out separately for the cost of electrical power and energy for the user and the nation(table 5). For the nation's perspective, net initial expenditure of retrofitting the solar film is negative. This means the benefits of capacity reduction and the peak power demand reduction of retrofitting the film exceeds the cost of film. The annual electricity savings is an added advantage. However, for the users perspective, due to the electricity being highly subsidized, retrofitting of the solar film is not very encouraging as it has a pay back period of over 40 years, which is significantly more than the film life.

RESULTS AND DISCUSSIONS

- Besides enhancing the thermal comfort during the peak summer period, the solar film was found to reduce the peak cooling demand by 6.7% in a residential villa which originally had windows with double clear glasses. The benefit of retrofitting solar film with single glazed windows is going to be significantly higher.
- Retrofitting the windows with solar film reduced the peak power demand of the A/C system by 4.7%, This reduction, similar to the reduction in cooling demand is going to be significantly higher for villas with single glazed windows..
- The financial benefits of the reduced cooling capacity for the A/C systems and its power demand were found to exceed the installed cost of the solar film. The reduction in annual energy consumption 9763.9 kWh/y was an added advantage.

CONCLUSIONS AND RECOMMENDATIONS

1. Solar film are easy to install in the existing buildings and need no maintenance.
2. In view of their cost-effectiveness, MEW should promote their large scale application as a technique for national load management,
3. Solar film offers a good solution for buildings which are deficient in cooling capacity and suffer from solar glare.

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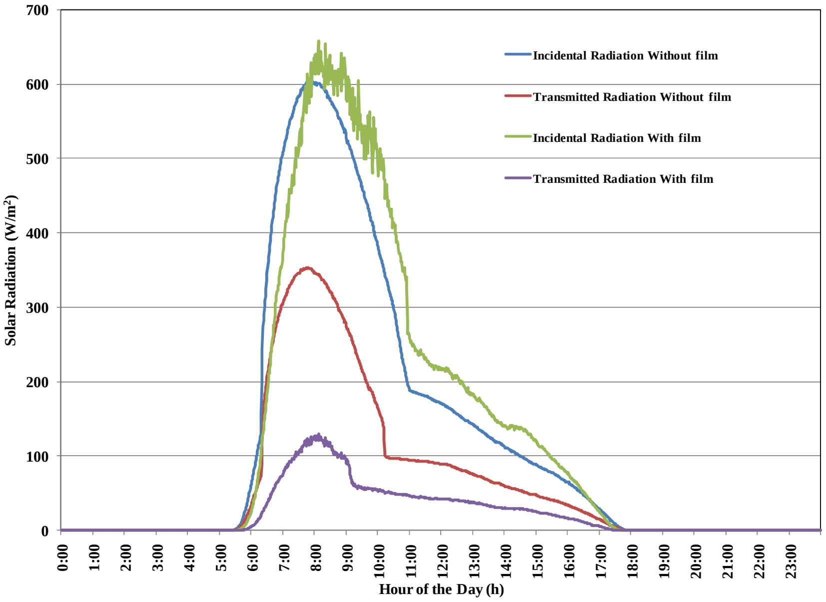

Fig 1. Incidental and transmitted global radiation on the east window

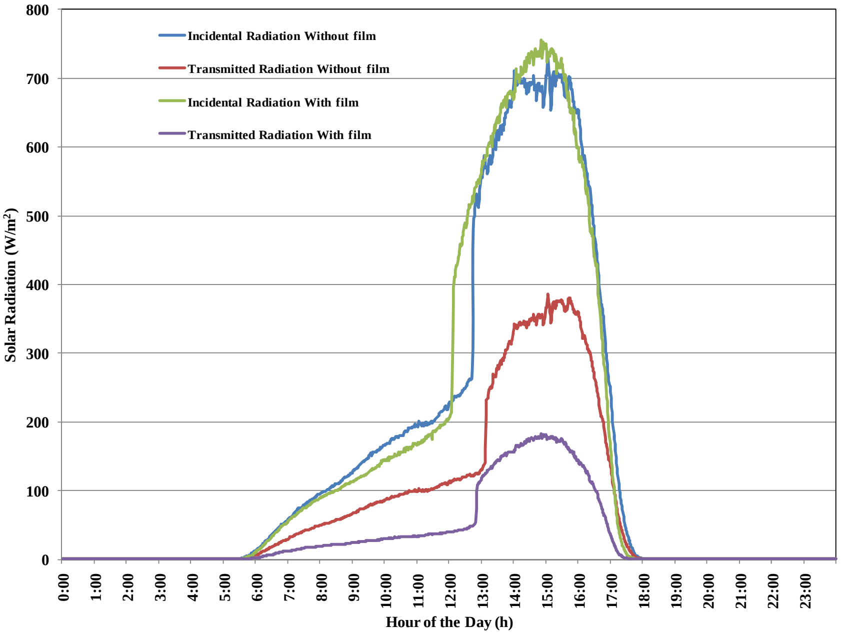

Fig 2. Incidental and transmitted global radiation on the west window

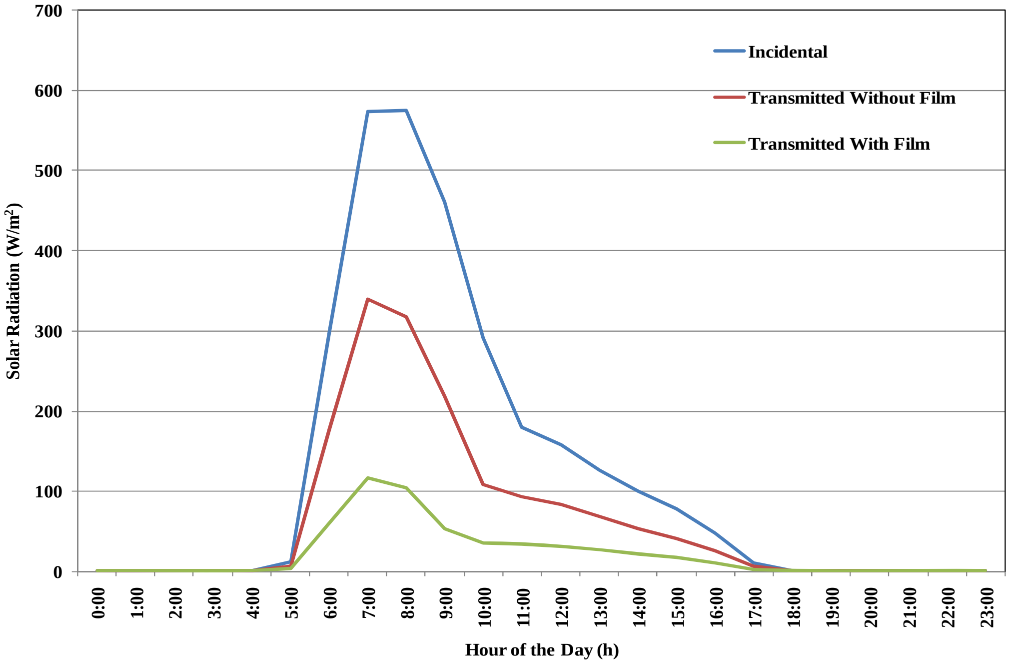

Fig. 3. Hourly Incidental and transmitted global radiation on the east window.

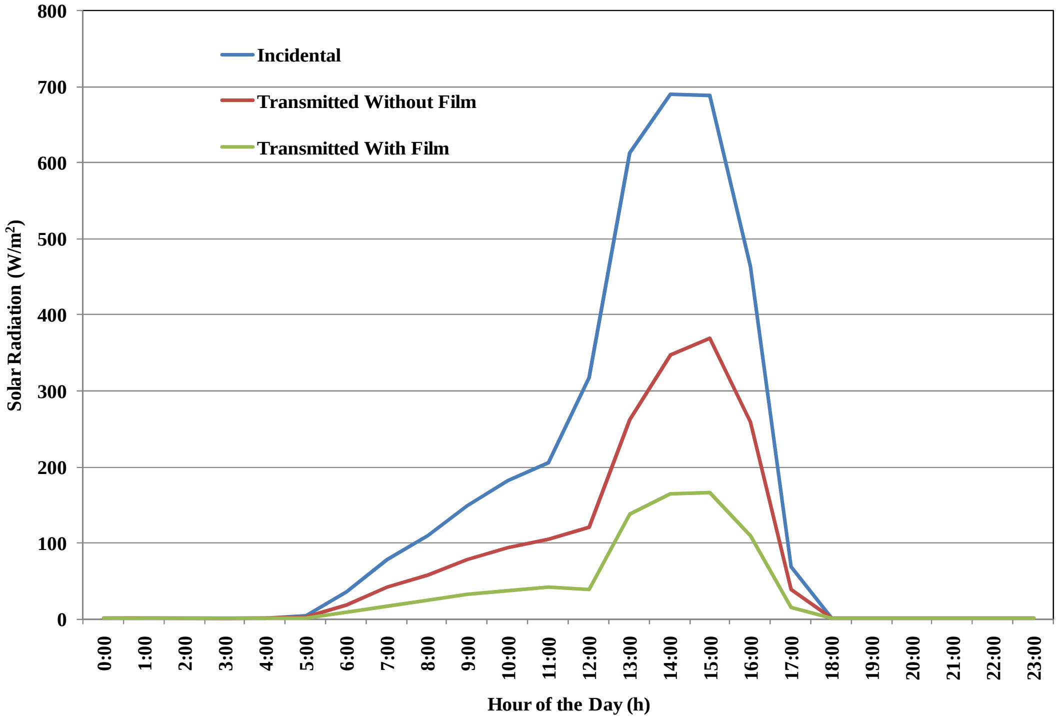

Fig. 4. Hourly Incidental and transmitted global radiation on the west window

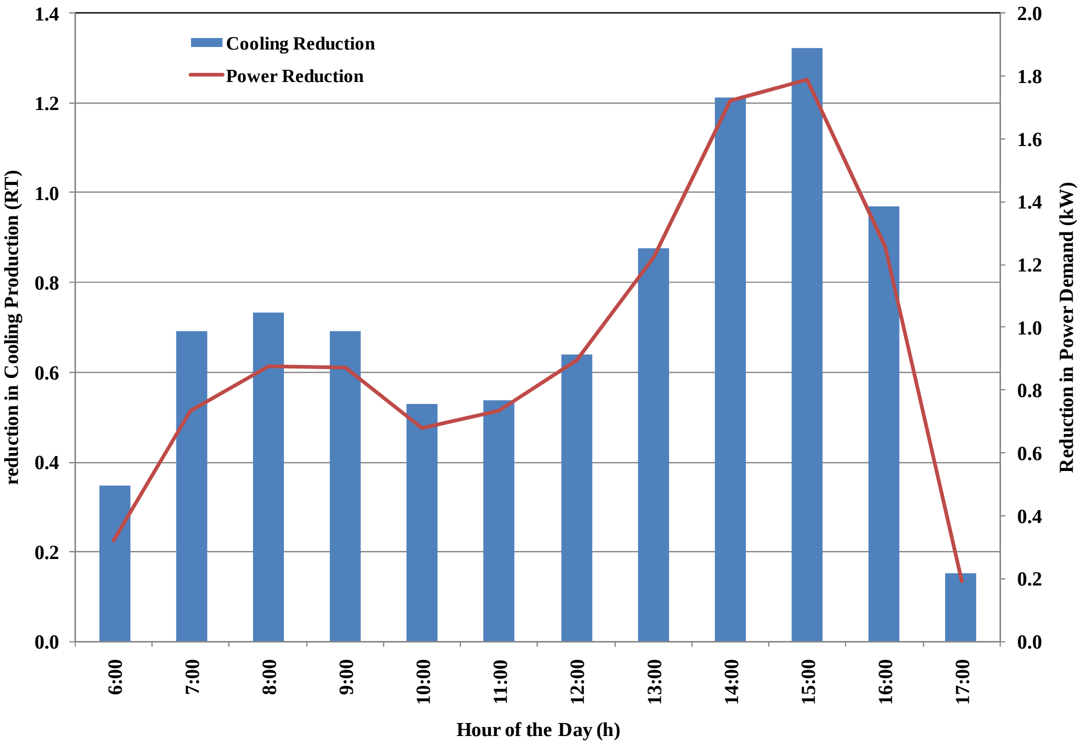

Fig.5. Hourly reduction in cooling and power demand for the villa.

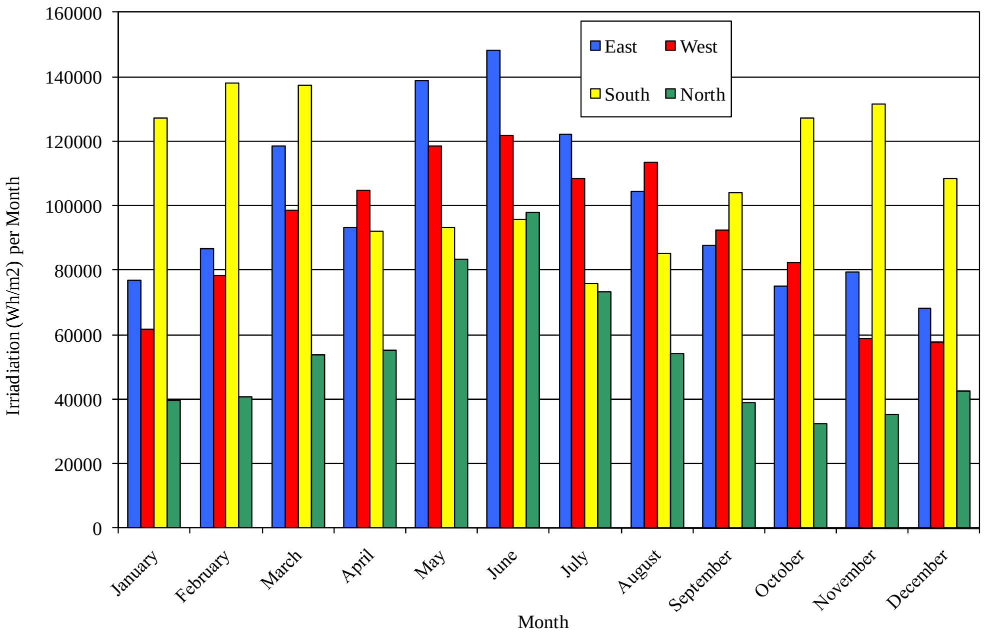

Fig.6. Monthly irradiation on plane vertical surface facing the cardinal directions (after correction)

Table 1. Details of the AC System

Location	Qty	Make	Model	Total Capacity (Btu/h) 115^{o} F	Total Power (kW)	Power Rating (kW/RT)
Basement Floor	2	Goodman	CKF60-5/A60-2	45,300	13.08	1.74
Ground Floor	2	coolex	PNG-076	66,380	16.06	1.45
First	1	coolex	PNG-076	66,380	8.03	1.45
Floor	1	coolex	PNG-090	85,890	11.67	1.63
Second Floor	1	Goodman	CKF60-5/A60-2	45,300	6.54	1.74

Table 2.The Technical Specifications of Instruments

Name of the instrument	Measuring variable	Manufacturer
Power Analyzer	Total Power consumption of the villa, Individual power consumption of A/C units	HIOKI, Japan
Ambient Temperature/ Relative Humidity Datalogger	Ambient Temperature/ Relative Humidity	HOBO (Onset Computers, USA)
Miniature Temperature/ Relative Humidity Data logger	Indoor air temperature , Relative Humidity, Light, Supply air temperature, Return air temperature	HOBO (Onset Computers, USA)
Pyranometers with Data logger	Global radiation inside and outside window	Onset Computers, USA

Table 3. Estimation for Monthly Energy Savings

Month	Incidental Radiation, kWh/m^2/month		Reduction in heat gain, RTh	Average Ambient Temp. during Sunshine hours, Deg C	Power Rating, Kw/RT	Energy Saving, kWh
	East	West				
January	77.0	61.8	N A	11.5	N A	
February	86.6	78.2		15.6		
March	118.5	98.5	1126.7	25.0	0.67	760.1
April	93.2	104.6	1027.4	28.8	0.84	866.7
May	139.0	118.5	1337.4	35.3	1.13	1510.0
June	148.2	121.7	1401.5	35.4	1.13	1586.3
July	122.1	108.3	1196.5	37.6	1.23	1471.8
August	104.5	113.4	1131.5	38.5	1.27	1435.3
September	87.6	92.6	935.9	35.3	1.13	1057.1
October	75.0	82.3	817.3	29.5	0.87	714.1
November	79.5	58.7	717.6	21.1	0.51	362.5
December	68.4	57.6	NA	15.7	N A	
Annual Total	1199.5	1096.3	9691.9			9763.9
Summer Total	967.6	898.7				
Winter Total	231.9	197.6				

Table 4. Parameters for Cost Benefit Analysis

Parameters	Values
AC Capacity installed, RT	25.8
Total Cost KD*	8200
KD/RT	317.8
Cost of film KD/m2	50
Area covered, m2	30.44
Reduction in Cooling Demand, RT	1.7
Reduction in peak power demand, kW	2.8
Annual Energy Saving, kWh	9764
Cost for Power Production and Distribution for MEW, KD/kW	400
Cost of Cable Connection to the User, kD/kW	50
Cost of Electricity for user, kD/kWh	0.002
Cost of Electricity for MEW without equipment, kD/kWh	0.024

*1 KD = 3.3 US$

Table 5. Pay Back Period for the User and the Nation

Parameters	User	Nation
Reductions in Capital Cost of AC System, KD*	540.3	540.3
Reductions in Power Cost, KD	140	1120
Reductions in Capital Cost, KD	680.3	1660.3
Expenditure incurred in film installation, KD	1522	1522
Net Initial Expenditure, KD	841.7	-138.3
Annual Cost of Energy Saved, KD	19.5	234.3
Pay Back Period, years	43.1	N/A

*1 KD = 3.3 US$