Design, Fabrication and Performance Evaluation of Awning/Canopy for Thermal Comfortability

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Abstract— This paper presents the design, fabrication and performance evaluation of retractable awning/canopy system for thermal comfortability. It consists of frame (mild steel bars), linear actuator, fabric (acrylic), adapter, roller pathways and photo sensor (for easiness of control). After fabrication and coupling of the whole components of the retractable awning and connecting to the adapter and power source for performance test evaluation, it was observed that, the actuator arm which was coupled to the fabric began projecting outward and once the photo sensor was shaded from sunlight using a dark material, the fabric retracted into the roller. Also it was noted that, shading the window provided a reduced solar heat gain factor of 28.16W as compared to the solar gain factor of 498.54 W before shading the window with a cooling load of 415.37 W achieved. This can be incorporated into a building plans especially those at the sun heating direction and temperature region to reduce inner temperature aid air-conditioner loading for longer life and efficient operation.

Keywords— Retractable Awning; Thermal comfortability; Performance evaluation; Heat gain factor: Cooling load

1 INTRODUCTION

Ever before the advent of modern day technology, man has actually starts developing means of surviving and balancing the force of weather variability with human comfortability through various means. This range from the simplest crude implement to the most sophisticated devices. For many centuries, man has tried to condition the atmosphere around him, but the weather change could be quite unpredictable even though the limits to this change can be presumed. Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is accessed by subjective evaluation. As a result, maintaining thermal comfort for occupants of buildings and other enclosures is therefore, one of the important goals of Heating, Ventilation and Air conditioning (HVAC) design engineers (ANSI/ASHRAE, 2013). Findings have shown that more energy is being transferred through doors and windows with approximately 20 percent of air conditioner load, from solar radiation through doors and windows (Dubois, 1997). However thermal neutrality is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. The main factors that influence thermal comfort are those that determine heat gain and loss, namely metabolic rate clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity as well as Psychological parameters such as individual expectations (Dubois, 1997). Those factors and many others can be held accountable for the thermal imbalance in human comfortability.

Commercial buildings with large glazed surfaces may easily suffer from overheating problems or large peak cooling loads. Solar shading devices can significantly reduce these cooling loads, improve thermal comfort and reduce potential glare problems. Most studies aimed at quantifying the reduction in heat flow through windows with various types of shading, showed that the shading devices affect heat flow through windows significantly, especially when installed on single pane, clear glass windows. Grasso et al (1990) reported that venetian blinds, draperies and roller shades reduce heat through the window by at least 25% with improved thermal resistance of windows by 40 %. In a related work of Horridge et al (1983), most shading devices improve the window's thermal resistance by up to 70%. Moreover, ETSU (990) demonstrated that thermal effects of net curtains or venetian blinds are negligible while light curtains reduce heat losses by 20% and heavy curtains by 40%. Few other studies attempted to assess the heat loss reduction provided by shading devices coupled with double pane windows. It can generally be inferred that, most authors agreed that venetian blinds, draperies and roller shades inside single pane, clear glass windows reduce heat losses by 25-40%. Metallic coated shades inside windows reduce heat losses by 45-58% depending on the material and mounting method used (Dubois, 1997; Littlefair, 1999).

There exist many mechanisms for conditioning the atmospheric temperature in a room or space and one of the many available conditioning mechanisms is an Awning. It is a secondary covering attachment to the exterior wall of a building typically composed of canvas woven of acrylic, cotton or polyester yarn, or vinyl laminated to polyester fabric that is stretched tightly over a light structure of aluminium, iron, steel and possibly wood or transparent material for weather protection and aesthetic looks (Dubois, 1997; DeDear & Brager, 1998). Apart from aesthetic benefit, An Awning also regulates the amount of sunlight, rain and wind that enters into a room thereby protecting the house wares, paints and furniture from premature fading (Alchin, 2008). The location of an awning on a building may be above a window, a door, or above the area along a sidewalk. With the addition of columns an awning becomes a canopy, which is able to extend further from a building. Moreover, awnings contribute more to sustainable buildings by providing a cooling system and energy savings via reduction of direct solar gain through windows and doors. Other benefit include reduction in peak electricity demand through reduced mechanical equipment such air conditioner load costs. Awning could be manually or electrically operated with each of them with their associated benefit and limitation. Such benefit may include low-cost, flexibility and comfortability. In this work, the awning was designed and controlled by a photosensor for easiness of control and comfortability

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A photosensor is an electronic component that detects the presence of visible light, infrared transmission (IR), and/or ultraviolet (UV) energy. Most photo sensors consist of semiconductor having a property called photoconductivity, in which the electrical conductance varies depending on the intensity of radiation striking the material (http//www.en.Wikipedia.org/ Photosensor). Till date, modern day houses are still faced with the problem of sunlight reflection through the windows leading to degradation of household equipment, fading of paints and unnecessary heating of the room and thermal discomfort for occupants in the building. In this paper, a retractable photo sensor window awning was designed, fabricated and evaluated for performance for regulating the amount of sunlight that enters a room. The design only considers solar radiation shading excluding wind and rainfall.

2 MATERIALS AND METHOD

2.1 Design Consideration and Material Selection

The Awning was designed by considering and using environmental conditions, material availability, space ambient temperature, window dimension (1200 x 1200 mm), awning dimension (25mm projection at 150 from the wall), wall and window orientation (south facing), indoor shading material (Venetian Blind) and the design month (21st February) in the region (Ilorin, latitude 80 North). Other design parameters notations used include:

- depth of shadow cast by horizontal width 'd' above the window = y,
- width of shadow cast by vertical projection = x
- solar azimuth angle = $\emptyset$, wall azimuth angle = γ, and solar altitude = β
- awning projection height and width are 'd' and 'h' respectively and
- angle of a vertical plane normal to the wall makes with the south = Ψ
- Window's length and width = (l_w and ω)

2.2 Design Calculation for the Shading Area Provided

For south facing window, Ψ = 0

$\gamma = \emptyset \pm \Psi = \emptyset$ $(since\ for\ south\ facing\ window, \Psi = 0)$

$\emptyset = 39^0,\ \beta = 66^0,\ (from\ appendix\ C)$

$d = \cos 75^0\ \times 250\ mm = 64.70\ mm$

$h = \tan 75^0\ \times 64.70\ mm = 241.46\ mm$

$x = d \tan\gamma = 0$ $(since\ there\ is\ no\ vertical\ projection)$

$y = d\ \tan\ 66/cos39 = 186.99\ mm$

$$Sunlit\ area\ (A) = \left(l_w - (y+h)\right) \times \omega \quad (1)$$

$A = 925860\ mm^2 = 0.925\ m^2$

2.3 Design Calculation for the Cooling load without External Shading

2.3.1 Solar heat gain through the window without indoor shading (q_{sg})

$$\boldsymbol{q_{sg}} = A_w\ (SC)(SHGF) \quad (2)$$

Where; A_w, SC & $SHGF$ are window's area, shagging coefficient and solar heat gain factor respectively.

$A = 1440000\ mm^2 = 1.44\ m^2; SC = 1.0, and$

$SHGF = 110Btu/ft^2$

$= 346.21W/m^2$; $see\ appendix\ A\ andB$

From (2): $\boldsymbol{q_{sg}} = 498.54\ W$

2.4 Design Calculation for the Cooling load with External and Indoor Shading

Solar heat gain through the window without external and indoor shading $(\boldsymbol{q_{sg}})$e

$$(\boldsymbol{q_{sg}})_e = A_s\ (SC)(SHGF)(CLF) \quad (3)$$

$where\ A_s$ = area of the shaded portion; CLF= cooling load factor at 13:00 Hrs. = 0.8 (ASHRAE, 1997)

$$A_s = (y+h) \times\ \omega \quad (4)$$

But y =186.99 mm; h = 241.46 mm and ω = 1200mm

Therefore; $A_s = 514140\ mm^2 = 0.5141\ m^2$

From appendix A (ASHRAE, 1997), SC = 0.64 and $SHGF$ = 34 Btu/ft2 = 107.01 W/m2

Using (3) $(\boldsymbol{q_{sg}})_e$ = 28.16 W

Solar heat gain through the window with external shading and without indoor shading $(\boldsymbol{q_{sg}})_i$ is given by Equation (5)

$$(\mathrm{q_{sg}})_\mathrm{i} = A\ (SC)(SHGF) \quad (5)$$

$A_s\ and\ SHGF$ is as in (4) and SC is as (3) above

Hence; $(\mathrm{q_{sg}})_\mathrm{i} = 55.01\ W$

The cooling load $(\mathrm{q_{sg}})$ is determined using Equation (6)

$$\text{Cooling load} = \{\mathrm{q}_{sg} - (q_{sg})_i\ + (q_{sg})_e\} \quad (6)$$

Therefore; the Cooling load = 415.37 W

2.5 Design Calculation for the Load which the Linear Actuator Arm Would Carry

$$Mass\ (M_f)\ of\ the\ fabric = \rho V \quad (7)$$

Where ρ, V are fabric's density and volume respectively

$$V = l \times b \times t \quad (8)$$

$l = 250\ mm, b = 1200\ mm\ and\ t = 2\ mm$

$\rho = 1170\ Kg/m^3$

V = 600000 mm3 = 0.00060 m3

Hence;M_f=0.702kg,

$Mass\ (M_r)\ of\ the\ 1200\ mm\ length\ of\ roller\ bar$

$$M_r = \rho_r V_r \quad (9)$$

$\rho_r; V_r$ are density and volume of the rod

$\rho_r = 7861.093\ Kg/m^3$

$$V = area\ \times lenght \quad (10)$$

$$A_r = \pi d^2/4\ where\ d = 30\ mm \quad (11)$$

$A_r = 706.86 = 0.0007\ m^3$

Also from Equation (9) M_r = 6.66 Kg

The total load (M_T) to be carry by the actuator is given by:

$$M_T = (M_F + M_R)g \quad (12)$$

M_T = 72.22 N

Since the mass of the load the actuator is to carry does not exceed the maximum load of the actuator by the manufacturer which is 150 N, then actuator speed would not be affected by the load

2.6 Material

The materials used for the fabrication of the Awning were selected from economic and user friendly point of view for cost effective, availability, affordability, durability as well as serviceability of the equipment for domestic use.

i. Acrylic fabric made from a polymer (polyacrylonitrile) with lightweight, soft and washable. It was selected due to its resistance to moths, chemicals, and deterioration from sunlight.
ii. Linear actuator: This was used because a linear motion was required in designing the awning.

iii. Adapter: This provides an external power supply.
iv. A photosensor: It converts the light energy whether visible or in the infra-red parts of the spectrum into an electrical signal output and mild steel due to its high strength to weight ratio.


a b

Fig. 1: (a) photo-sensor solar tracker (b) a linear actuator

2.7 Fabrication Process

Two mild steel bars were cut with a hack saw to length 1930mm and two other mild steel bars were cut to length 2200mm, the four bars were welded together using electric arc welding to form a rectangular frame. Four mild steels bars were cut with a hacksaw to length 460mm and were welded to two mild steel bars of length 1200mm each to form the two supports. The support bars were then welded to each end of the rectangular frame to form a strong base. Two mild steel bars were cut to length 460mm and welded to a mild steel bar of length 1930mm to form a base for housing the roller and for which the fabric would travel. Furthermore, the base which serves as the housing for the roller was welded to the frame. The roller was then coupled to the frame using screws of 10mm diameter along with the linear actuator. The photosensor was then coupled to the top of the frame with its micro controller screwed to the side of the frame using 10mm diameter screws (see Fig. 2)

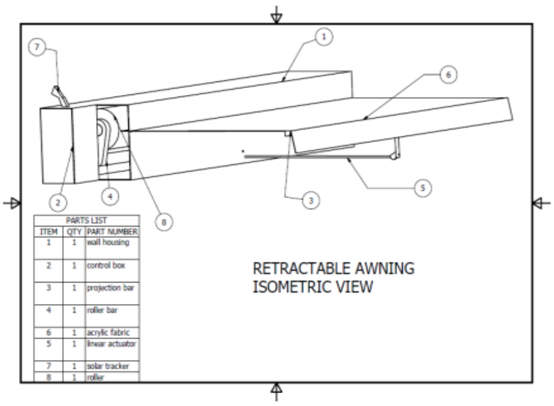

Fig. 2: Isometric View of the Designed working Drawing of Retractable Awning

2.8 Principle of Operation and Performance Evaluation Test

A linear actuator of stroke length 250mm was attached to a projector bar with the aid of a link. One end of a fabric is attached to the projector bar, and the other end of the fabric was attached to a roller (projector roller). Both the projector roller and the non - moving part of the linear actuator were coupled to a mild steel frame/stand to replicate a wall. The mild steel frame at one end has the control panel in which a photosensor (solar tracker) was attached and coupled to the frame above all the other components with the AC/DC adapter connected to a wall socket or any other source of power.

3 Results and Discussion

With source of power is on, the solar tracker detects the presence of sunlight and sends a signal to the control panel which in turn ejects the actuator arm along with the fabric fully, the actuator arm and the fabric would be fully withdrawn once it is dark with no sunlight. The actuator would initiate a linear motion which will push the fabric out of the projector roller as its arm is ejected and also withdraw the fabric back into the roller once the arm is being withdrawn. The fabric rolls out and withdraws inward easily with the help of the projector roller (see Fig. 3). The designed working drawing for the fabricated awning was as presented in Fig. 3). Performance evaluation test carried out on the designed and fabricated retractable awning system reveal the solar heat gain, temperature with time during shading the window and not with the retractable awning system (see Table 1)

Fig. 3: Photograph of Designed and Fabricated Retractable Awning Device

Table 1: Performance of the Retractable Awning with Temperature and Time

S / N	Time Tested	Ambient Temperature without shading (° C)	Actuator Projection Length	Ambient Temperature with external shading (° C)
1	6.00	25.0	0 mm	25.0
2	8.00	25.8	0 mm	25.8
3	10.00	29.0	250 mm	27.4
4	12.00	33.0	250 mm	27.9
5	14.00	34.0	250 mm	28.1
6	16.00	34.0	250 mm	28.1
7	18.00	31.0	250 mm	27.5

The result of the performance evaluation once it was powered, revealed that the linear actuator gave the estimated linear projection and the projector roller eject and withdrew the fabric freely without any hindrance with good sensitivity obtained from the photo sensor. It was also noticed that, the actuator arm which was coupled to the fabric began projecting outward and once the photo sensor was shaded from sunlight using a dark material, the fabric retracted into the roller. After carrying continuous test, it was noticed that the shading the awning system provided to the window, reduced the solar heat gain by a factor of 28.16W as compared to the solar gain factor of 498.54 W before shading the window with a cooling load of 415.37 W was achieved. The result of performance evaluation of the retractable awning with temperature and time during and without shading was as presented in table 1. It was observed that with retractable shading, the temperature obtained was lower and within the ambient temperature regardless of the time of test as compared with when the retractable device was not in use.

4 Conclusion

From the results and discussion above, the following conclusions can be reached;

1. The fabricated retractable awning can result in cooling energy savings by reducing direct solar heat gain through the window
2. It also aids fast cooling of air-conditioned room with improve thermal comfort
3. The automation of the window awning shading system reduces the stress involved in its operation, hence enhanced comfortability.

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Appendices

Appendix A

SHADING COEFFICIENT FROM ASHRAE HANDBOOK, 1997 Fundamentals

Types of glass	Thickness (mm)	No indoor shading	Shading Coefficient			
			Venetian blinds		Rollers shades	
			Medium	Light	Dark	Light
Single glass						
Regular sheet	3	1.00	0.64	0.55	0.59	0.25
Plate	6-12	0.95	0.64	0.55	0.59	0.25
Heat-absorbing	6	0.70	0.57	0.53	0.40	0.30
	10	0.50	0.54	0.52	0.40	0.28
Double glass						
Regular sheet	3	0.90	0.57	0.51	0,60	0.25
Plate	6	0.83	0.57	0.51	0.60	0.25
Reflective	6	0.2-0.4	0.2-0.33			

Cooling-load factors for glass with interior shading, north latitudes From ASHRAE HANDBOOK, 1997 Fundamentals

Cooling-load factors for glass with interior shading, north latitudes From ASHRAE HANDBOOK, 1997 Fundamentals

Solar Time h	Window facing								
	N	NE	E	SE	S	SW	W	NW	Hor
6	0.73	0.56	0.47	0.30	0.09	0.07	0.06	0.07	0.12
7	0.66	0.76	0.72	0.57	0.16	0.11	0.09	0.11	0.27
8	0.65	0.74	0.80	0.74	0.23	0.14	0.11	0.14	0.44
9	0.73	0.58	0.76	0.81	0.38	0.16	0.13	0.17	0.59
10	0.80	0.37	0.62	0.79	0.58	0.19	0.15	0.19	0.72
11	0.86	0.29	0.41	0.68	0.75	0.22	0.16	0.20	0.81
12	0.89	0.27	0.27	0.49	0.83	0.38	0.7	0.21	0.85
13	0.89	0.26	0.24	0.33	0.80	0.59	0.31	0.22	0.85
14	0.86	0.24	0.22	0.28	0.68	0.75	0.53	0.30	0.81
15	0.82	0.22	0.20	0.25	0.50	0.83	0.72	0.52	0.71
16	0.75	0.20	0.17	0.22	0.35	0.81	0.82	0.73	0.58
17	0.75	0.16	0.14	0.18	0.27	0.69	0.81	0.82	0.42
18	0.91	0.12	0.11	0.13	0.19	0.45	0.61	0.69	0.25

Appendix B

Maximum solar-heat gain factor for sunlit glass W/m^2 From ASHRAE HANDBOOK, 1997 Fundamentals

	N/shade	NE/NW	E/Wu	SE/SW	S	Hor.
32° north latitude						
Dec	69	69	510	775	795	500
Jan, Nov	75	90	550	785	775	555
Feb, Oct	85	205	645	780	700	685
Mar,	100	330	695	700	545	780
Sept	115	450	700	580	355	845
Apr, Aug	120	530	685	480	230	865
May, July	140	555	675	440	190	870
June						
40° north latitude						
Dec	57	57	475	730	800	355
Jan, Nov	63	63	480	755	795	420
Feb, Oct	80	155	575	760	750	565
Mar,	95	285	660	730	640	690
Sept	110	435	690	630	475	790
Apr, Aug	120	515	690	545	350	830
May, July	150	540	680	510	300	840
June						