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The Effect of All Kinds of Canopies on Reduction of Energy Consumption in Hot and Dry Climates

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Abstract

Canopies exist as a part of a building or separate from the building facade, and it can be significantly employed to control the amount of solar radiation to the aspects of the building exposed to light, to reduce the peak temperature, to supply cooling requirements and to boost the quality of indoors natural lighting. The present research was conducted with aim of studying the effect of all kinds of canopies on reduction of energy consumption in commercial buildings in Yazd, using external canopies for one year in the commercial building in Yazd. This is an empirical research. Angstrom-Prescott formula was used to measure the amount of input energy by canopy in indoor commercial spaces. The results of paired-t test in SPSS indicates that regarding all external canopies – except for horizontal aluminum plates with a blade angle of 90 - there is a significant relationship between using various kinds of external canopies. Regarding internal canopies, the results of paired-t test also indicate there is a significant relationship between the use of various kinds of these canopies and the reduction of radiated solar energy. In other words using various kinds of blinds and curtains for indoor space of Yazd commercial building effects the reduction of energy consumption. Also comparing the efficiency of various canopies against the same input energy, it can be said that the highest efficiency of external canopy is related to external blind with a blade angle of 90˚, and the least efficiency is related to aluminum blade with an angle of 90˚. Also, the highest efficiency of internal canopy is related to internal blind with a 90˚ blade, and the least is related to internal blind with 0˚ blade.

Keywords: Canopy, commercial building, reducing energy consumption, hot and dry, yazd.

Introduction

Regarding the present and potential limitations, the recognition of environmental capabilities and potentials plays an important role in environmental planning. The climatic aspects of architecture are one of the interesting issues in studies related to the role of climatic factors in housing and human living space. One of the important aims of climate-suited architecture is the thermal comfort of space users.

Regarding the necessity of climate-based design two points may be mentioned: 1. Buildings with climate-suited design are of higher quality in terms of thermal comfort. 2. Harmony with climatic conditions saves the fuel which is needed for thermal control of such buildings.

In desert cities such as Yazd, due to high input radiation energy and hot and dry climate, we need to create facilities for thermal comfort of indoors space users, preventing direct sunlight or reducing it. Regarding commercial spaces which require seller's constant indoor presence, this issue gains significant importance. Canopies are employed to control the amount of sunshine and to reduce input energy in climates with high number of hot days during the year. Meanwhile, the introduction and recognition of various types of canopies is necessary in order to control the density of solar radiation and to compare their different models to recognize the optimized model.

The innovative aspect of the present research can be comparing the effect of some characteristics of canopies – including criteria such as the effect of color and angle of the blade on reducing the consumption of solar radiation and also studying the thermal comfort in commercial buildings.

The research questions are: Is the application of various types of canopies in the climate of Yazd effective in reducing solar radiation?, Which type of external and internal canopies is more effective in reducing the input solar energy?
Also, the present research aims to investigate the effect and to compare various types of canopy in reducing energy consumption in the climate of Yazd commercial buildings.

Theoretical Framework: Using canopies, whether as a part of building or as a separated part of the building, can be effective in reducing the indoor temperature, creating pleasant weather and making use of natural light. The place and type of canopies depend on the direction of sunshine in relation to the intended facade[1].

Numerous researches have been conducted regarding the role of canopies in controlling energy consumption in buildings. In a study conducted by Roy in 2004, five types of different canopies were compared in terms of the amount of saving in cooling system and lighting system, and in the end he came to the conclusion that the place and features of canopy have a significant on the amount of building's required heating and cooling load and the comfort of users near the window, the results indicate that in the best condition it will save about 60 % in cooling system[2].

In their article, David et al have proposed simple criteria for comparing visual and thermal performance of different types of solar canopies in non-residential buildings. These criteria can be extracted from numerical simulations from energy plus software, which include the analysis of daylight and thermal analysis. In the present article an office building is studied in order to evaluate the efficiency of various types of solar canopy. Using the proposed criteria helps select and determine the size of the most efficient solar canopy for the case study.

In an article "Climatic design of residential buildings in Sabzevar, emphasizing building orientation and the depth of canopy", Hossein Abadi et al. using building eco-climatic diagram determine the thermal and environmental requirements of buildings (taking into consideration climatic elements such as the maximum and minimum temperature and relative humidity) and finally the principles that should be considered in designing buildings. They come to the conclusion that the facade or main facades of a building should be located in a direction that receive less energy during hot periods and more solar energy during cold periods. The results of this research show that in unidirectional, 15 and 30 degrees east and in bilateral buildings, 15 degrees east and North-South direction respectively are the best direction for the position of the building in Sabzevar[3].

In a research "The comparison of five biotic and non-biotic methods of shading in dry and warm regions (Case study: Yazd university campus)", Ali Akbar Karimiyan et al investigate temperature factors, light intensity, canopy-building expenses by using five different types of structures including date mat, straw mat, board, tarpaulin and iranit, the height, canopy cover and vigor of five species of climbing plants including Forsythia suspense (thumb.) vahl, Rosa banksiaeAit. , Wistariasinensis (sims.) DC. ,Loniceracaprifoliom L., Vitisvinifera L. in the form of a completely randomized design with 3 replicationsin the Yazd university campus for three years[4].

In this research, in regard with the importance of building canopy in the crowded paths of the university, different groups using campus will be surveyed. The findings of this research showed the existence of significant difference between structures and control (without campus) in terms of reducing temperature and light intensity, however, the temperature difference among treatments was not significant while light intensity difference among treatments was significant ($P<0.05$). In this relationship, regarding 3 treatments of Date mat, Board and Tarpulin no difference was observed. Comparison of costs also showed statistical difference among structures. In regard with green canopy, there was no significant difference among species in terms of height, canopy cover level and freshness and in this case, Wistariasinensis (sims.) DC species had a significant difference with other treatments in terms of height. In terms of canopy cover and freshness, there was no significant difference among three species including Wistariasinensis (sims.) DC, Rosa banksiaeAit and Loniceracaprifoliom L ($P>0.05$). However, these three species had a significant difference with the other two species including Vitisvinifera L. and Forsythia suspense (Thumb.) vahl and most of the users emphasized on the importance of making a canopy decorated with the climbing plants[4].

Canopy Types: Canopy categorization could be done in the light of two perspectives.

Canopy installation place: From the perspective of installation place, canopies can be divided into interior and external categories. The efficiency of these canopies is higher than that of the interior canopies which only causes a 5-10 % penetration of energy into the room. Such canopies are installed out of buildings and on their windows. They include blind, external curtains, awning curtains and horizontal aluminum plates. The most useful feature of these canopies is that they keep the sun's heat out of the building[5]. Compared with other external curtains, curtains are lighter[6], and horizontal aluminum plate are used in the southern façade when sun angle is obtuse[1].

Interior shutters and canopies belong to this group. These canopies can only cause a 20-25% reduction of sun' thermal effect on a room[7]. Figure 1 shows different interior and external canopies.

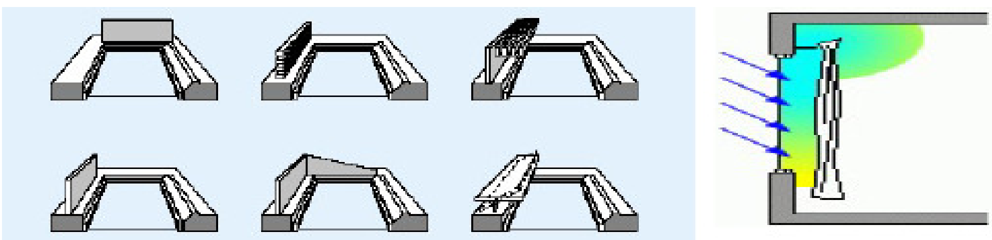

Figure-1
Different types of canopies: external canopies (left figure) and interior canopies (right figure)

Mobility of a Canopy: Fixed canopies are stable during all seasons. Their efficiency in terms of providing a useful shade on a window depends on the position of the building and also on the daily and annual changes of sun position.

Mobile canopies are mobile, and their geometrical shapes does not have an important impact on their efficiency in terms of providing shades and preventing direct radiation of sunlight into the room since these canopies can be changed desirably based on need. On the other hand, the efficiencies of such canopies are different, and depend on the building's natural ventilation and canopies installation position in relation with the window[8, 9].

Research data: At first, average radiated energy amount per month into space without canopy was collected in order of months of the year by Iran's Meteorological Organization resources in which the highest radiated energy in cm^2 of a window in a commercial building's south wall in Yazd equals 10866.8 calories per cm^2 and it is related to the 7^{th} month (July) and the lowest radiated energy in cm^2 of a window in a commercial building's south wall equals 5249.6 calories per cm^2 and it is related to the second month. (February) (table-1)

Methodology

In this research, Angstrom-Prescott formula was used to measure incoming energy amount using canopy in the interior of commercial spaces. The information related to the incoming energy amount was also obtained in the interior of commercial spaces by Iran's Meteorological Organization resources. Using SPSS, paired t-test was used to measure the amount of relationship among using a variety of canopies to reduce solar energy.

The radiated energy amount into space using internal and external canopies is computed by Angstrom-Prescott formula[10, 11]:

$$\frac{\bar{H}}{\bar{H}_o} = a + b\frac{\bar{n}}{\bar{N}}$$

In this relationship, $\bar{H}$ is solar energy using internal canopy, $\bar{H}$ solar energy out of atmosphere, n is the average hours the sun shines brightly into space and N is also the average maximum hours the sun is in the sky.

In fact, the above methodology can be considered as an empirical research. In this research, in order to discover the causal relationship, energy consumption reduction and the effect of a variety of canopies have been considered as the independent variable and dependent variable respectively.

Investigation of a Case Study (Yazd): Yazd city is the capital of Yazd province and it is located in southeast of Iran with hot and dry climate. (figure-2) this city is in hot and dry climate and located at 31 54 'north latitude', 54° 24 east longitude (figure-1) and with the altitude of 1230 above sea level and no humid month with an average annual rainfall of only 60 millimeters, average temperature of 20/23° C and relative humidity of 27/3 percent. The upper limit of thermal comfort of this city is 21/8° C in summer, its upper limit is 28/65° C and its lower limit of thermal limit in winter is 20/4° C and its upper limit is 24/8° C.

Table-1
Total radiated energy in different months in Yazd city in normal mode

Months of Year	1	2	3	4	5	6	7	8	9	10	11	12
Total Radiated Energy per Month (cal/cm2	5730.04	5249.6	5535.8	6004.8	7514.3	10101.2	10866.8	10655.7	10493.2	9159.0	8086.9	6351.7

Source: Meteorological Organization

Figure-2
Geographical position of Yazd city in the country and Yazd province Findings

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Results and Discussion

Finding: The values including a and b for Yazd city are 0.345 and 0.389 respectively[12, 13]. Therefore, the average radiated energy in Yazd city are computed using each of canopies through the following formula:

$$\frac{\overline{H}}{\overline{H_o}} = 0.345 + 0.389 \frac{\overline{n}}{\overline{N}}$$

As it can be seen in tables 2 and 3, incoming solar radiation energy per month was obtained using the above formula and difference of hours of bright sun radiating indoors by canopy. In addition, figure 3 and 4 show the comparison of the effect of different canopies on the amount of incoming energy and comparison between solar radiation energy before using the canopy and that of after using it.

Table-2
Total radiated energy in different months in Yazd city using external canopies by Angstrom-Prescottt Formula

Months of the Year	Incoming Energy without Using Canopy per Month	Incoming Energy of Blind by 0° Blade per Month	Incoming Energy of Blind by 45° Blind per Month	Incoming Energy of Blind by 90° Blind per Month	Incoming Energy of Dark External Curtain per Month	Incoming Energy of Light External Curtain per Month	Incoming Energy of Dark Awning per Month	Incoming Energy of Light Awning per Month	Incoming Energy of 45° Aluminum Blade per Month	Incoming Energy of 90° Aluminum Blade per Month
1	5730.4	1899.3	839.5	409.2	447.3	581.2	712	2397.91	1595.88	3069
2	5249.6	1337.2	915.9	430.5	469.245	611.31	749.07	2522.73	1678.95	3228.75
3	5535.8	1811.5	1439.5	614.6	669.914	872.732	1069.404	3601.556	2396.94	4609.5
4	6004.8	3043.8	2397.1	934.0	1018.06	1326.28	1625.16	5473.24	3642.6	7005
5	7514.3	3621.6	2830.08	1042.9	1136.761	1480.918	1814.646	6111.394	4067.31	7821.75
6	10101.2	3446.8	2694.9	984.8	1073.432	1398.416	1713.552	5770.928	3840.72	7386
7	108668	3598.2	2812.2	1029.7	1122.373	1462.174	1791.678	6034.042	4015.83	7722.75
8	10655.7	3536.8	2780.2	1062.9	1158.561	1509.318	1849.446	6228.594	4145.31	7971.75
9	10493.2	2487.2	1976.2	834.1	909.169	1184.422	1451.334	4887.826	3252.99	6255.75
10	9159.0	1707.1	1343.5	626.3	682.667	889.346	1089.762	3760.118	2442.57	4697.25
11	8086.9	1651.8	967.1	467.3	509.357	663.566	813.102	2738.378	1822.47	3504.75
12	6351.7	2131.1	809.8	404.9	441.341	574.958	704.526	2372.714	1579.11	3036.75

Source: author, * Incoming solar energy unit is based on cal/cm2.

Table-3
Total radiated energy in different months in Yazd city using internal canopies by Ångström-Prescott Formula

Months of the Year	Incoming Energy without Using Canopy per Month	Incoming Energy of internal Blind with the angle of 0° blade per Month	Incoming Energy of internal Blind with the angle of 45° blade per Month	Incoming Energy of internal Blind with the angle of 90° blade per Month	Incoming Energy of dark internal Curtain per Month	Incoming Energy of Internal Light Curtain per Month
1	5730.4	1178.496	822.492	621.984	1047.552	842.952
2	5249.6	1239.84	865.305	654.36	1102.08	886.83
3	5535.8	1770.048	1235.346	934.192	1573.376	1266.076
4	6004.8	2689.92	1877.34	1419.68	2391.04	1924.04
5	7514.3	3003.552	2096.229	1585.208	2669.824	2148.374
6	10101.2	2836.224	1979.448	1496.896	2521.088	2028.688
7	10866.8	2965.536	2069.697	1565.144	2636.032	2121.182
8	10655.7	3061.152	2136.429	1615.608	2721.024	2189.574
9	10493.2	240202.8	1676.541	1267.832	2135.296	1718.246
10	9159.0	1803.744	1258.863	951.976	1603.328	1290.178
11	8086.9	1345.824	939.273	710.296	1196.288	962.638
12	6351.7	1166.112	813.849	615.448	1036.544	834.094

Source: author, * Incoming solar energy unit is based on cal/cm2.

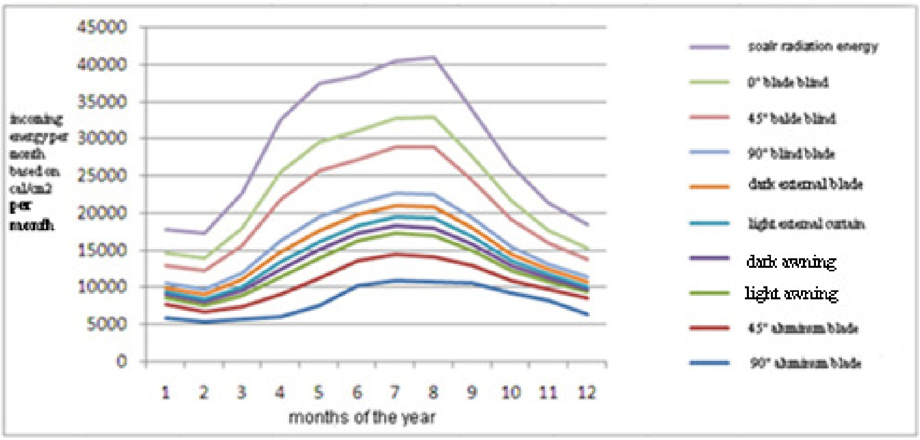

Figure -3
Comparison of incoming solar energy using a variety of external canopies and without using it

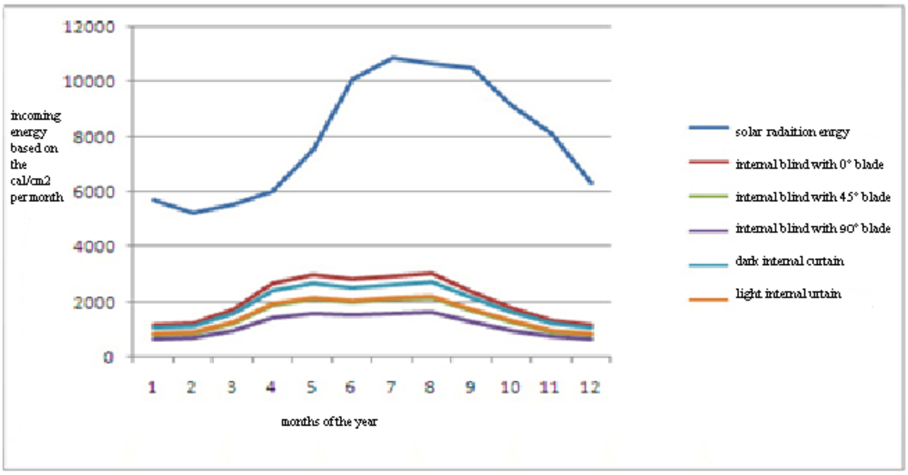

Figure-4
Comparison of incoming solar energy using a variety of internal canopies and without using it

Paired T-Test: Paired t-test was used to investigate the effect of kind of canopy on energy consumption reduction. Using this test makes it clear that whether there is significant relationship between a special canopy in difference of energy amount before using it and that of without using it or not. If the significance level was smaller than 0.05, this relationship was significant. This means that the used canopy has a significant effect on solar energy amount reduction. In this research, using paired t-test, comparison of average radiated energy comparison per month was investigated separately in two stages including before and after using the canopy and it was determined that the difference of average radiated energy per month, except the horizontal aluminum plates with the angle of 90° blade (sig=0.26), is statistically significant in this research. In regard with the effect of color it is also possible to analyze that light color has a less effect on energy consumption reduction so that the significance level of light awning is more than dark awning (table-4). Regarding the rest of canopies, the amount is sig<0.05 and it can be concluded that there is a significant relationship between using these canopies and incoming solar energy amount reduction.

In other words, using external blind with a variety of blade angles 0°-90°, dark and light awning canopy and horizontal aluminum plates with the angle of 45° have an effect on radiated energy consumption reduction in the climate of Yazd city. Except the horizontal aluminum plates with the angle of 90° because of the fact that the significance level is higher than 0.05 (sig=0.26), it has no significant relationship with energy consumption reduction, that is; using horizontal aluminum plates with the angle of 90° blade in the climate of Yazd has not significant effect on energy consumption reduction in the building.

In regard with internal canopies, it can also be said that there is a significant relationship between using a variety of these canopies and solar energy consumption reduction. (Sig=0.000) in other words, using a variety of blinds and curtains in commercial building of Yazd is effective in energy consumption reduction (table-5).

Table-4
Results of paired t-test to evaluate the effect of a variety of external canopies on energy consumption reduction in the commercial building of Yazd city

	Kind of Canopy	Average Radiated Energy per Month during Year without Using Canopy	Average Incoming Energy per Month during Year by Canopy	Standard Deviation	Significance Level	Degrees of Freedom
1	External Blind with the Angle of 0° Blade	7422.7	2648.9	902.1	0.000	9
2	External Blind with the angle of 45° Blade	7422.7	2002.9	807.3	0.000	9
3	External Blind with the angle of 90° Blade	7422.7	796.9	2555.57	0.000	9
4	Dark External Curtain	7422.7	868.6	278.5	0.000	9
5	Light External Curtain	7422.7	1131.6	362.9	0.000	9
6	Dark Awning	7422.7	1386.6	444.7	0.000	9
7	Light Awning	7422.7	4669.8	1497.6	0.030	9
8	Horizontal Aluminum Plates with the Angle of 45° Blade	7422.7	3107.9	996.7	0.01	9
9	Horizontal Aluminum Plates with the Angle of 90° Blade	7422.7	5976.7	1916.7	0.260	9

Source: author

Table-5
Results of paired t-test to evaluate the effect of a variety of internal canopies on energy consumption reduction in the commercial building of Yazd city

		Average Radiated Energy per Month during Year	Average Incoming Energy per Month during Year	Standard Deviation	Significance Level	Degrees of Freedom
1	Internal Blind with the Angle of 0° blade	7422.7	2295.07	736	0.000	9
2	Internal Blind with the Angle of 45° blade	7422.7	1601.7	513.6	0.000	9
3	Internal Blind with the Angle of 90° blade	7422.7	1211.2	388.4	0.000	9
4	Dark Internal Curtain	7422.7	1641.6	526.4	0.000	9
5	Light Internal Curtain	7422.7	1641.6	526.4	0.000	9

Source: author

Conclusion

In this research, in order to evaluate the effect of a variety of canopies on energy consumption reduction in Yazd city, using Angstrom-Prescottt Formula and investigation of solar energy variables using indoors canopy, out of atmosphere solar energy, average of hours the sun shines into space brightly and also average of maximum hours the sun is present in the sky and using coefficients specific to Yazd city, incoming solar energy amount in the case of using different external and internal canopies were investigated. The highest efficiency of external canopy which equals the lowest incoming solar energy is related to the external blind with the angle of 90° blade and the lowest efficiency is related to the 90° aluminum blade. Figure 5 shows the average incoming radiation energy in seasons of the year using a variety of canopies.

The highest efficiency of internal canopy equaling the least solar incoming energy is related to the internal blind with the angle of 90° blade and the lowest efficiency is related to the internal blind with the 0° blade. Figure 6 shows the average incoming radiation energy in seasons of the year using a variety of internal canopy.

Then, solar incoming energy amount without using these canopies was examined, these two were compared using paired t-test and significance level of relationship between using a kind of canopy and energy consumption reduction was obtained.

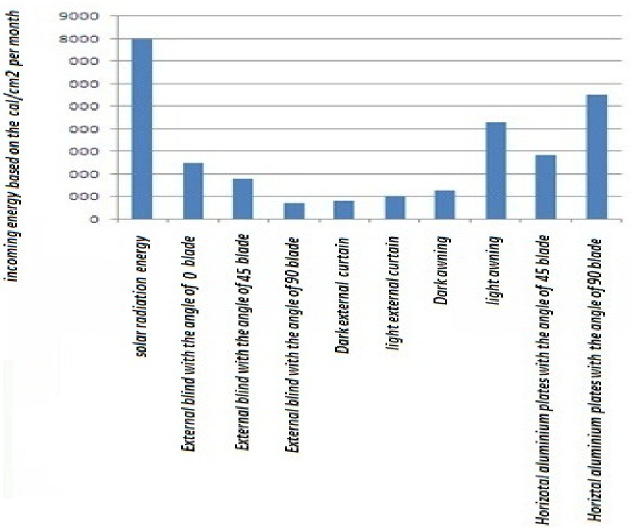

Figure-5
Average incoming radiation energy in seasons of the year using external canopies

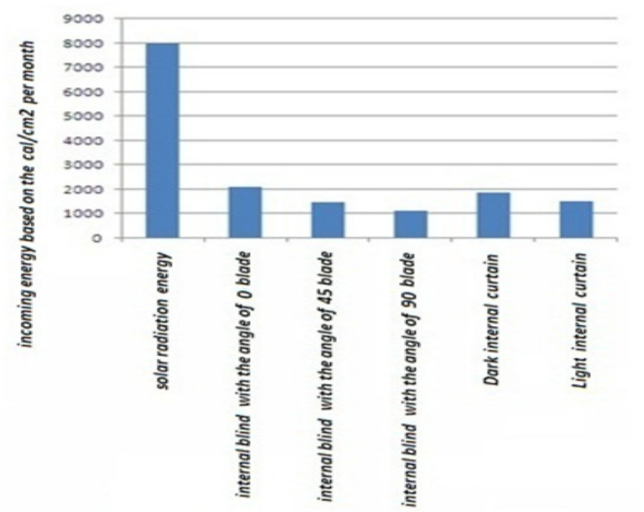

Figure-6
Average incoming radiation energy in seasons of the year using internal canopies

Using paired t-test and comparison of average radiated energy comparison per month in two stages including before and after using the canopy, it was determined that the difference of average radiated energy per month in all external and internal canopies, except the horizontal aluminum plates with the angle of 90° blade (sig=0.26), is statistically significant in this research and it can be concluded that there is a significant relationship between using a variety of the canopies in this research including external and internal blinds with the angle of 45° blade, external and internal dark curtains, internal and external light curtains, dark and light awnings and horizontal aluminum plates with the angle of 45° blade, except the horizontal aluminum plates with the angle of 90° blade with incoming solar energy amount reduction.

Compared to the canopy place, it can be said that the effect of internal canopies is more than external canopies. In regard with the effect of color, it can also be evaluated that light color has a lower effect on energy consumption reduction in a way that significance level of light awning is higher than that of dark awning.

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