

# PASSIVE SOLAR CONTROL - A METHODOLOGY FOR THE PROMOTION OF ENVIRONMENTAL CONSCIOUS DESIGN OF ANKARA AIRPORT

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## ABSTRACT

The aim of this paper is to emphasize the significance of the passive solar control in buildings for minimizing the operational energy costs, and to encourage architects to consider solar control as a part of their design process. To support this idea, “The Passive Solar Control and Overhang Design Project” designed for TAV Anatolia, Esenboğa Airport in Ankara will be investigated as a case study.

The project targeted an optimal solar control, thus decreasing the heating cost in winter by allowing maximum solar energy gain and decreasing the cooling cost in summer by allowing minimum energy gain from façades. This was achieved by designing overhang and fins in adequate sizes in accordance with the simulation results. Various computer programs were used and the project was formulated in three stages. First stage included the simulation of the building with its existing situation to determine the shadowing of building itself with current volumes and with its own eaves and overhangs. This analysis guided to the determination of the critical facades as well. Second stage was completed with different options of the overhang and fin sizes for each façade according to the placement of devices. Considering the facade configuration, the architectural team chose one of the options. The project was concluded with the final analysis of the building with the chosen overhang and fin combination. It should be stressed that this project was conducted in close cooperation with the architectural team of the building and became the part of the design process. Particularly concentrating on the methods of the passive solar control, this paper will also discuss the obtained results and their importance in terms of the solar control and energy saving.

**Keywords:** Passive Solar Control, Fixed External Shading Devices, Energy Saving, Optimization

## **PASSIVE SOLAR CONTROL IN ARCHITECTURE**

Airports are typically large, isolated, mostly low-rise shade-free structures that are visited by millions of people every year. With the increase in the demand for fast transportation, airports throughout the world are constantly being expanded and upgraded. “Modern man becomes universal”, states Hardison; “No longer quite an individual, no longer quite the product of a unique geography and culture, he moves from one climate-controlled shopping mall to another, from one airport to the next, from one Holiday Inn to its successor three hundred miles down the road; but somehow his location never changes.” (Hardison, 1993)

An important issue for energy saving in architecture, especially in airport buildings, which are to be designed with large spaces lit by huge glass façades, is the use of passive solar techniques that provide the reduction of the thermal gains and electrical loads of air-conditioned systems. Such strategies developed for energy efficient architecture combined with optimized material configuration and the proper amount of thermal insulation in the building envelope help to reduce the energy demands of the building and production of building related carbon dioxide (CO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>) and nitrogen oxide (NO<sub>x</sub>) emission into the atmosphere. A precisely calculated and designed sun control and shading system is a vital element in building that employs passive solar heating or day lighting. Fixed, manual and automatic movable, internal and external shading devices are among the tools that are mentioned as the tools available to optimize daylight. (Gugliermetti & Bisegna, 2005)

Many researches had been carried on methods of calculation of performances of shading devices. (El-Refaie, 1987; Kabre, 1999; Ralegaonkar & Gupta, 2005; Marsh, 2003). The different tools are designed to analyze the shading devices for different performance indicators but it is not possible to evaluate the amount of indoor illumination, or the amount of shade casted on window instantly, due to the changing position of sun on sky. But, it is no doubt that computer analysis still provides a certain speed for repetitive calculations throughout the process.

It is common knowledge that the sun’s position in the sky changes from season to season and hourly throughout a day. The sun is higher in the sky in the summer than in winter, and that the sun rises south of east in winter and north of east in summer. Therefore using a computer tool during the analysis process, which has to consider sun’s position, provides several advantages; it gives certain flexibility to the designer as it makes study possible to evaluate design alternatives with different orientations within a short time; it enables to conduct analysis in complex building geometries.

## **FIXED EXTERNAL SHADING DEVICES FOR SOLAR CONTROL**

During the first stages of design of a building, generally the geometrical factors related to the building's shape are the main issues that architect deals with. In these early stages, it is useful to determine the solar potential of the building and the surrounding areas, providing the exposure of the elevations and sidewalks to the winter sun, and creating the necessary shading during the critical hours of the summer days.

It is very important to be able to determine the optimal shading system of windows. The shading devices that are not fixed to building are not considered to be architectural elements; but rather a tool of retrofication to a building. On the other hand, external shading devices have always been indicated as a very simple, low-cost and common solution to control the incoming of natural light and they should be considered as an important architectural element as they both affect the façades and indoor lighting level (Ralegaonkar & Gupta, 2005). Beam radiation, which penetrates inside the buildings through various openings, can be controlled using sunshades for the temperature regulation. The important property of an external static sun-shading device is that it blocks the sun before it enters to the space, and thus provides the solar energy to be kept out. Internal shading devices may be effective in controlling day lighting but there is always a problem of decreasing the cooling loads after solar radiation enters to the space. External shading devices that are most effective in solar control must be designed by considering the solar positions throughout the year.

In light of these factors, in this study the design principles of external louvers for glazed openings with respect to different façade orientations for solar control were discussed

## **METHODOLOGY**

With advances in computer development, building energy simulation, which provides effective design decision support, has been proved useful in analyzing day lighting schemes. The shading strategy adapted in this study is providing that the window surface will always be shaded optimum in the profile. The optimal length of an overhang was calculated depending on the size and the orientation of the window. The required period for control is the time during which the building façade must be shaded avoiding the penetration of direct solar radiation into the building. In this analysis the length of the required period of shading is determined according to climatic and programmatic considerations.

In this paper, using the section of the façade or profile, a one-dimension analysis is used to calculate optimum dimensions of interacting shading devices by means of simple computer program software. The data for location, window height, and

orientation are defined to the computer program software and the process is repeated for each different internal placement of overhang. The horizontal and vertical shadow profiles are generated for modules of building with different height for required latitude and longitude and at any time or date. The result is a vector diagram of shadow line projections cast by the façade elements. However using these diagrams to create a meaningful shadow map remains a manual task requiring an understanding of how the diagrams should be interpreted and applied to a 3D structure.

To design the most efficient solar shading device, the direction of sunlight at solar noon, two months either side of the winter solstice and the direction of sunlight at solar noon, two months either side of the summer solstice is depicted on the side view of the windowpane. To obtain the shade, the position and size of the overhang is determined so that the winter sunlight points at the front of the window head, and the summer sunlight points at the rear of the windowsill. This will ensure that the strongest sunlight is blocked during the summer months, and admitted during the winter months as it is desirable to design a shade so that the window is fully shaded in the summer to minimize heat loading, and fully exposed in the winter to maximize heat gain in the climatic conditions of Ankara where the study is conducted ([www.cadinfo.net/reviews/shadowfx.htm](http://www.cadinfo.net/reviews/shadowfx.htm)). After one dimension optimization of the interactions between building parts, overhang and fins, the performance of the shadowed surface is calculated in 3D simulations to validate the model.

## **PASSIVE SOLAR CONTROL STRATEGIES FOR ESENBOĞA AIRPORT BUILDING**

An important issue that carries a solar control tool to success is that the planning team of a building has to agree on a control strategy that solar shading systems reflects the priorities of the designers and the functioning of the building. The design of effective shading devices depends on the solar orientation of a particular building façade. For instance, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high. However, the same horizontal device is ineffective at blocking low afternoon sun from entering west-facing windows during peak heat gain periods in the summer.

To properly design shading devices it is necessary to understand the position of the sun in the sky during the cooling season. The position of the sun is expressed in terms of altitude and azimuth angles. The backing theory for the solar motion and the solar projected angles can be found in previous literature (Budin & Budin, 1982). In the summer, peak sun angles occur at the solstice on June 21, but peak temperature and humidity are more likely to occur in August. ([www.wbdg.org/design/suncontrol.php](http://www.wbdg.org/design/suncontrol.php)).

This study, prepared for new airport building of Ankara, targeted an optimal solar control by decreasing the heating cost in winter allowing maximum solar energy gain and decreasing the cooling cost in summer allowing minimum energy gain. This was achieved by designing overhang and fins in adequate sizes in accordance with the simulation results.

The Passive Solar Control and Overhang Design Project designed for Esenboğa Airport in Ankara was planned to be performed in three stages. First stage included the simulation of the building with its existing situation to determine how the building casts shadows on itself with its own eaves and overhangs. This analysis guided to the determination of the critical façades as well. Second phase was completed with different options of the overhang and fin sizes (l) varying according to the distance (d) between two devices. Considering the appearance of the façade, the architectural team had selected one of the options. The project was concluded with the final analysis of the building with the chosen overhang and fin combination.

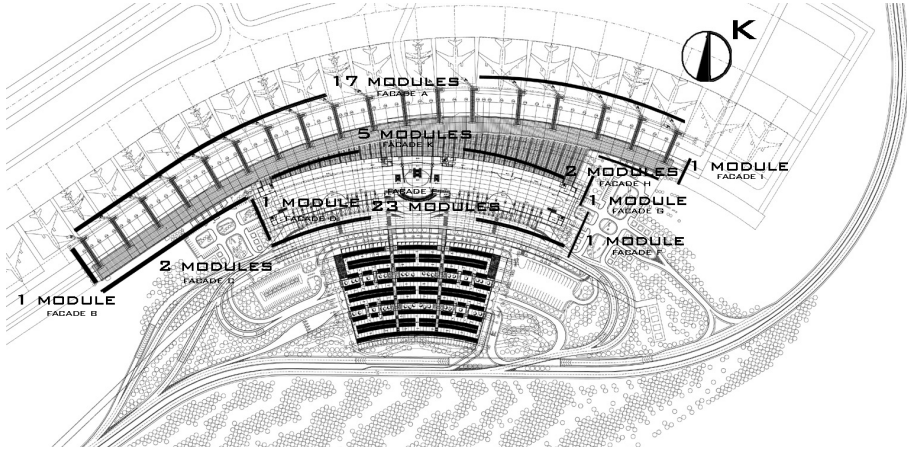
### **First Stage: Analysis of Base Case Situation**

Before starting any alteration it was significant to understand the current condition of the building in terms of its solar geometry. At the first stage of the project it was targeted to simulate the building with its existing situation; named as the base case, to determine the shadowing of building itself with current volumes and with its own eaves and façade elements. This analysis led to the determination of the critical façades. Even with computer programs used, which able to project shadows onto 3D building models, the design of an effective system is carried as a process of trial and error to a certain extend with manual computations. The complexity of the airport building required that the building is divided into small modules. The building was divided into 54 modules, each of which has a different orientation.

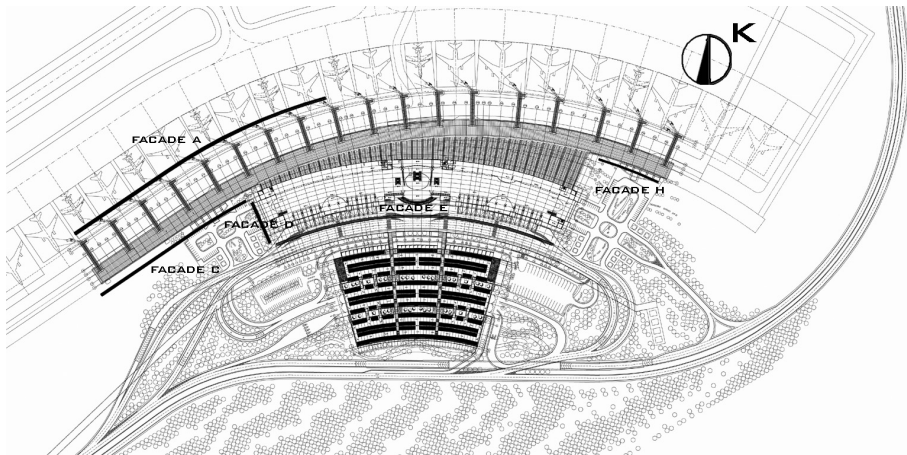
The angle between the normal of the each module and the north was calculated and the solar position of each module was investigated separately. For the determination of the critical façades, the shadow profiles of each module, from sunrise to the sunset were analyzed with 20 minutes time intervals. This analysis was conducted with the help of software programs and the numeric results were justified by 3D solar simulation of the building. For the analysis of the existing situation of the building, the 21<sup>st</sup> of June was selected as the critical day. After this investigation, the critical façades were determined as Façade A, Façade C, Façade D, Façade E and Façade H.

### **Second Stage: Determination of Optimal Shading Tools**

The time dependent value of the sunshade is a geometric variable, which depends on the shading device opening system, geometry, sun position, wall orientation,



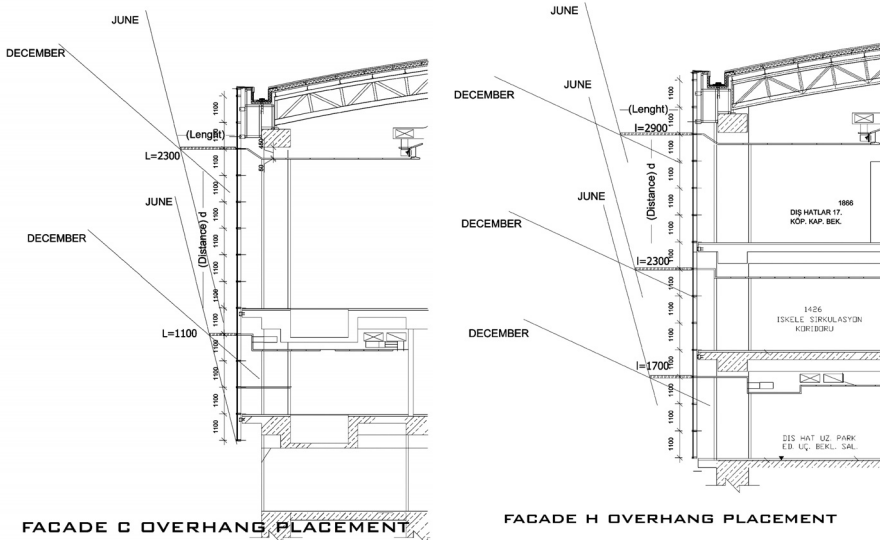
**Figure 1.** Plan of Airport Building Showing The Modulation of The Building (Architectural Drawing by TAV Anatolia, Esenboğa Investment Construction and Operation Co.)



**Figure 2.** Plan of Airport Building Showing The Critical Façades for Solar Control (Architectural Drawing by TAV Anatolia, Esenboğa Investment Construction and Operation Co.)

etc. An ideal shading device is expected to exclude solar radiation during over-heated periods and admit it during under-heated periods. For the determination of the overhang and fin sizes, the cooling season for Ankara had to be determined. This was achieved using 10-day averages acquired by 20-year hourly temperature data of Ankara. The days when outside temperature more than 21 C° was selected as the period in which cooling is compulsory, and to do so, the period from 21<sup>st</sup> of May to 30<sup>th</sup> of September were indicated as the over heating period of Ankara.

Different options of the overhang and fin sizes for each façade according to the placement of devices were offered to the architectural team enabling of the most appropriate one for each façade. A matrix showing combinations of shading device options for several intervals of placement (d) and device length (l) is prepared and the shadow rates of alternative combinations of the fin and overhangs were also submitted to the architectural team.



**Figure 3-4.** Module Sections for Façades C and H (Architectural drawing by TAV Anatolia, Esenboğa Investment Construction and Operation Co.)

This was an optimization process that has been carried by architectural group and the passive solar control group as well. The issue of depicting which type of solar control device was a problem that had many parameters including façade divisions and the problem the obstruction of the view of occupants inside in addition to the amount of shade wanted to be obtained.

The results revealed that the interval of placement (d) and the device length (l) are inversely proportional. The value of (d) decreases as the value of (l) increases (Tables 1-2). The trade off is achieved by discussing the most appropriate type of device with respect to (l) and (d). Overhangs have negligible effects on low morning and afternoon sunshine, therefore for the east, west, and north windows, which mainly receive low sunshine, a passive control with a combination of vertical fins and overhangs were suggested.

Third Stage: Re-evaluation of The Shadow Profile of The Airport with The Selected Overhang and Fin Combination

Table 1. Façade C Shading Device Alternatives

| Façade C (125 - 132 Angle Modules) |                   |              |       |      |      |      |      |      |      |      |      |      |
|------------------------------------|-------------------|--------------|-------|------|------|------|------|------|------|------|------|------|
| Shading device                     |                   | Alternatives |       |      |      |      |      |      |      |      |      |      |
|                                    |                   | A1           | A2    | A3   | A4   | A5   | A6   | A7   | A8   | A9   | A10  | A11  |
| Interval of placement (d)          |                   | 12100        | 11000 | 9900 | 8800 | 7700 | 6600 | 5500 | 4400 | 3300 | 2200 | 1100 |
| Device length (l) (mm)             | 125 Angled module | 3600         | 3300  | 3000 | 2600 | 2300 | 2000 | 1700 | 1300 | 1000 | 670  | 350  |
|                                    | 132 Angled module | N/A          | N/A   | 3500 | 3100 | 2700 | 2300 | 1950 | 1500 | 1100 | 770  | 400  |

Table 2. Façade H Shading Device Alternatives

| Façade H (176 - 179 Angle Modules) |              |      |      |      |      |      |      |      |
|------------------------------------|--------------|------|------|------|------|------|------|------|
| Shading device                     | Alternatives |      |      |      |      |      |      |      |
|                                    | A1           | A2   | A3   | A4   | A5   | A6   | A7   | A8   |
| Interval of Placement (d)          | 8800         | 7700 | 6600 | 5500 | 4400 | 3300 | 2200 | 1100 |
| Device length (l) (mm)             | 4600         | 3900 | 3500 | 2900 | 2300 | 1700 | 1100 | 600  |

The project was concluded with the final analysis of the building with the chosen overhang and fin combination selected by the architectural team. For Façade C and H due to their orientation towards south, overhangs situated with appropriate configuration were effective in terms of solar control. The figures 6 and 8 show the amount of increase in the shaded areas with the overhang installation.

To be able to depict the amount of shading provided throughout the complete cooling season the analyses is carried out for May, June, July, August and September. As mentioned previously to let the solar radiation inside for the heating season was the project strategy as well as blocking it during the cooling season. Therefore the condition for December is also given in the figures 7 and 9 for Façades C and H respectively below.

To evaluate the results of the project, it can be assessed that with its volumes and eaves the shadowing rate of the building is overall satisfactory except for the Facades A, C, and H, which were identified as the most critical facades. Particularly in the afternoon, the west oriented modules of Façade A are exposed to solar radiation coming almost parallel to the ground. This renders the single use of hor-

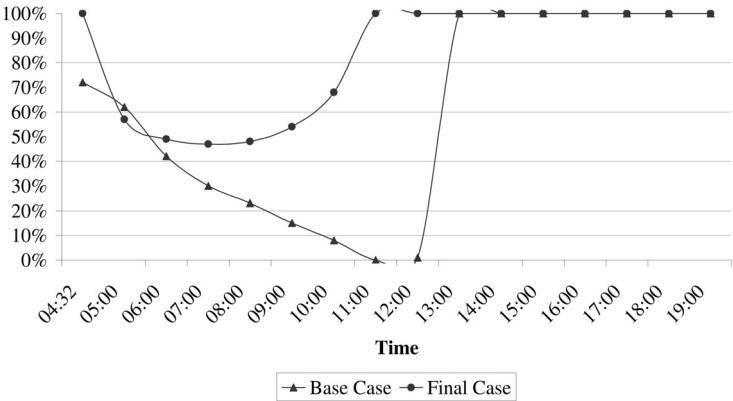


Figure 5. Shading Profile for Initial and Final Phases

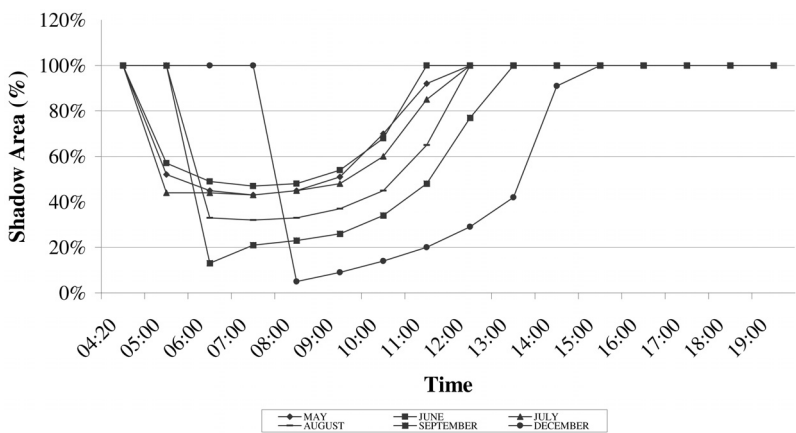
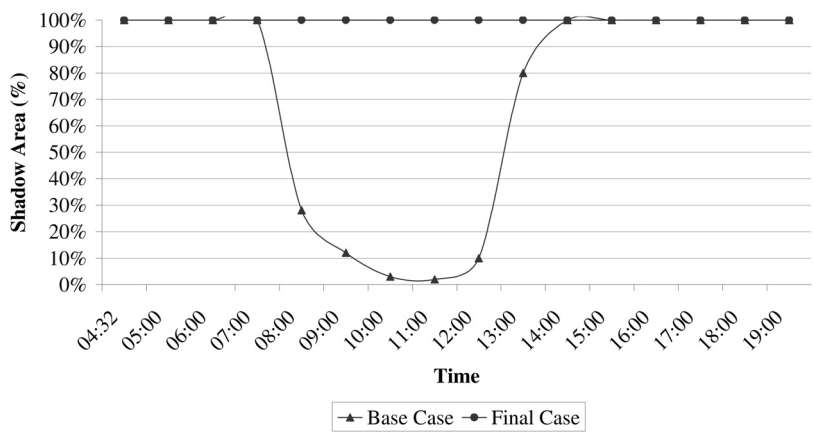


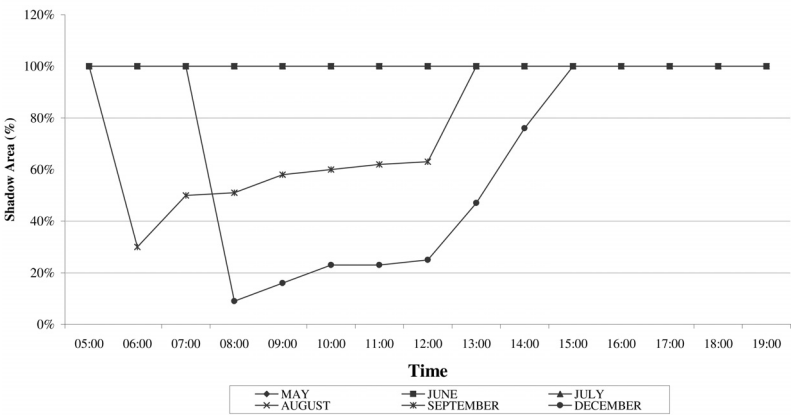
Figure 6. Yearly Shading Profile for Façade C

horizontal shading devices (overhangs) insufficient and requires the use of vertical ones as well (fins).

Therefore, for this section, several alternatives of fin and overhang combinations with their shadowing rates were offered to the selection of the architectural team. As the Facades C and H are exposed to the solar radiation only in the noon, different alternatives of horizontal shading devices were suggested for these facades.



**Figure 7.** Shading Profile for Initial and Final Phases for Façade H



**Figure 8.** Yearly Shading Profile for Façade H

## CONCLUSION

Overhangs on windows with dimensions based on precise estimations can have marked cooling load reductions in summer while having insignificant effects on the sunshine received by windows in winter. The results and optimum dimensions given for the width, and spacing of overhangs for new Airport building of Ankara is presented in this paper.

The shading devices can have a dramatic impact on the appearance of buildings, and because of this fact Passive Solar Control should be concerned in the early phases of the design process. This requires an integrated work with the design

team and it is a two-way process, as architectural concepts are effective on the determination of the optimization criteria of shading devices nearby the climatic condition and building usage, where the results of such an analysis are re-evaluated by architectural theme particularly when designing the building's facades. The results of such an integrated work are particularly valuable for the preparation of the mechanical projects and the calculation of the operational cost, and therefore they should be assessed by the mechanical engineers as inputs to calculate the cooling and heating loads of the relevant building.

This research aimed to stress the vital significance of the Passive Solar Control in buildings as a part of the design process and tried to offer a methodology for such a study exemplifying the Solar Control Project for Esenboğa Airport. The results of the project clearly showed that passive solar control in buildings, particularly in the public buildings, when large glass surfaces were concerned, not only decreases the operational cost, saving energy, but also provides thermally and visually comfortable environment for the users of the building.

## **ACKNOWLEDGEMENTS**

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