# Application of Fuzzy Logic in Interior Daylight Estimation

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**Abstract** - *The topic of Fuzzy Logic as a decision-making technique is introduced. It is recommended that applications of this technique could be effectively applied in the area of interior daylight evaluation. An example of such an application, the evaluation of average daylight factor for a side light office, is discussed and examples of the method are presented. Other possible design applications are suggested.*

**Résumé** - *Il est toujours difficile d'évaluer des phénomènes aléatoires tels que l'éclairement naturel. L'expérience du concepteur est souvent reconnue comme le meilleur outil pour évaluer de tels événements. Avec l'immense développement qu'a connu le domaine informatique, il est maintenant facile de pouvoir développer des algorithmes plus sensibles au caractère de l'analyse et du raisonnement humain utilisant des nouvelles techniques d'abstraction telles que la logique floue.*

**Key words**: Fuzzy sets - Day lighting - Daylight factor - Matlab.

## 1. INTRODUCTION

Even as rigorous numerical modelling daylight processes continues to improve in both spatial and temporal resolution, there will likely continue to be processes that elude explicit analytic solutions. Physical processes not yet well understood or those beyond the resolution of the models still need alternative methods for their analysis and subsequent prognosis. Random processes such as daylight, has always been difficult to evaluate.

Most experienced designers will quickly suggest that experience is the best tool for evaluating such events. With the rapidly evolving technologies in the field of day lighting, it is desirable to merge the experience of many designers with algorithms that may aid in difficult situations. Cognitive computing has been an emergent set of problem solving algorithms that attempt to imitate natural problem solving techniques. One such method is called Fuzzy Logic [1].

Fuzzy Logic is a simple yet very powerful problem solving technique with extensive applicability. It is currently used in the fields of business, systems control, electronics and traffic engineering. The technique can be used to generate solutions to problems based on ''vague, ambiguous, qualitative, incomplete or imprecise information''. There are many design difficulties that fit the previous description - where rigorous, analytical solutions do not exist. Fuzzy Logic is an extension of Fuzzy set theory that was developed approximately 30 years ago.

The paradoxical name requires a short explanation. The intent of Fuzzy set theory was to alleviate problems associated with traditional binary logic, where statements are exclusively true or false. Fuzzy Logic allows something to be partially true and partially false.

A simple example follows: Is a room with 3 % average daylight factor considered to be dark and dull ? Traditionally we must define a threshold over which an average daylight factor is considered a member of the bright set and under which he is not. Fuzzy Logic allows one to speak of a 5 % average daylight factor is both a member of the bright set and the medium set, and possibly even the dark set. It may be considered to a larger degree a member of the medium set than it is of the bright set. A room with 7 % average daylight factor will be to a higher degree a member of the bright set.

If a problem suggests there is some consequence related to the brightness of the room, then the consequence can be applied or inferred in relation to its degree of membership in the bright set.

Those are many instances within daylight modelling which cannot be easily handled by methods other than statistical methods and other less analytic methods. In some cases, decision trees or flow charts have been developed. However, these are based on traditional logic [2].

## 2. A FUZZY SYSTEM : INTERIOR DAYLIGHT DISTRIBUTION

The natural phenomenon chosen here to demonstrate this method is that of the interior day lighting estimation.

This problem was chosen since it is a common in architectural design. Several graphical methods have been developed and used over the years to aid in the prediction of the interior daylight repartition. Specifically, methods developed by the Building Research Station, have been taught for years [3]. The basic physical principles involved are thought to be well understood.

## 3. THE DAYLIGHT FACTOR CONCEPT

Daylight can be handled quantitatively in two ways:

a) By using luminous quantities (flux, illuminance), i.e., by assuming a set of outdoor values and calculating the resulting interior illuminances.
b) By using relative values (the daylight factor), i.e., by calculating the ratio of illuminance at appoint indoors to that outdoors. This ratio is constant for a given situation under widely varying outdoor lighting conditions of an unobstructed CIE overcast sky.

The daylight factor method is derived from first principles, which enables it to calculate accurately daylight for any point within a room and be applicable to wide range of window configurations. Later on, the method has been expanded to include CIE clear skies [4, 5].

The daylight factor is defined as the ratio of illuminance due to daylight at a point indoors on the work-plane to the simultaneous outdoor illuminance on a horizontal plane.

Another concept is often used in daylight design and window sizing especially at early design stages, is the average daylight factor over the working plane and average over all the interior surfaces.

The Average Daylight Factor is the arithmetic average of the daylight factors obtained throughout a space. The advantages of the average daylight factor are that it bears a close relationship with the subjective appraisal of lighting in a room and is less sensitive to changes in the sky luminance distribution and the positioning of the window in the window wall [6], [7].

## 4. SYSTEM INPUTS AND FUZZY SETS

Within the context of the current example of interior daylight estimation, general terms associated with Fuzzy Logic will be introduced.

In general, a problem to be solved is referred to as a *system*. *System inputs* are those physical variables that are thought to completely determine the solution(s) to the problem, or *system outputs*. In the current example the system output is the average daylight factor. System inputs to be used in this case are the values of openness, surface reflectance and the space geometry.

These system inputs are readily available, and their values are typically considered when an architect develops his scheme. It is understood at this point that there are other physical variables that designer may consider important in the lighting design of his project. The sky condition, the orientation of the facades, the daylighting systems, and even the surrounding environment are crucial in architectural design. However, the purpose here is to demonstrate the method in a general case.

The system inputs are categorized into physically significant domains called *fuzzy sets*. Fuzzy sets are simply qualitative descriptions of the chosen domains of the inputs, each of which is thought to have a specific effect on the output. Table (1) shows the fuzzy sets used in this example.

**Table 1**: Fuzzy Sets in the average daylight factor evaluation example

| Reflectance | Geometry | Opening |
|---|---|---|
| Dark | Shallow | Closed |
| Medium | Medium | Medium |
| Light | Deep | Open |
| Very Light | | Very Open |

The interpretation of the qualitative description of these fuzzy sets, and the physical effect on the interior daylight repartition should be obvious. The value of the current surface reflectance factor is categorized into one of four fuzzy sets: dark, medium, light and very light. Similarly, the value of the opening is described as closed, medium, open and very open. The geometry of the space is only characterized by one of three categories; the space is shallow, medium or deep.

The determination of the fuzzy sets is derived solely from experience. A developer of a fuzzy system must judiciously choose these categories such that reasonable systems outputs will be obtained. This is the critical process of tuning, or calibrating, the system. It is here where the experience of the system developer becomes very important [8].

The fuzzy sets are quantitatively defined by membership functions. These functions are typically very simple functions that cover a specified domain of the value of the system input. The functions are generally trapezoids, although simpler functions such as triangles and rectangles and even delta functions are often used. The fuzzy sets in this example are shown in figures 1 through 3.

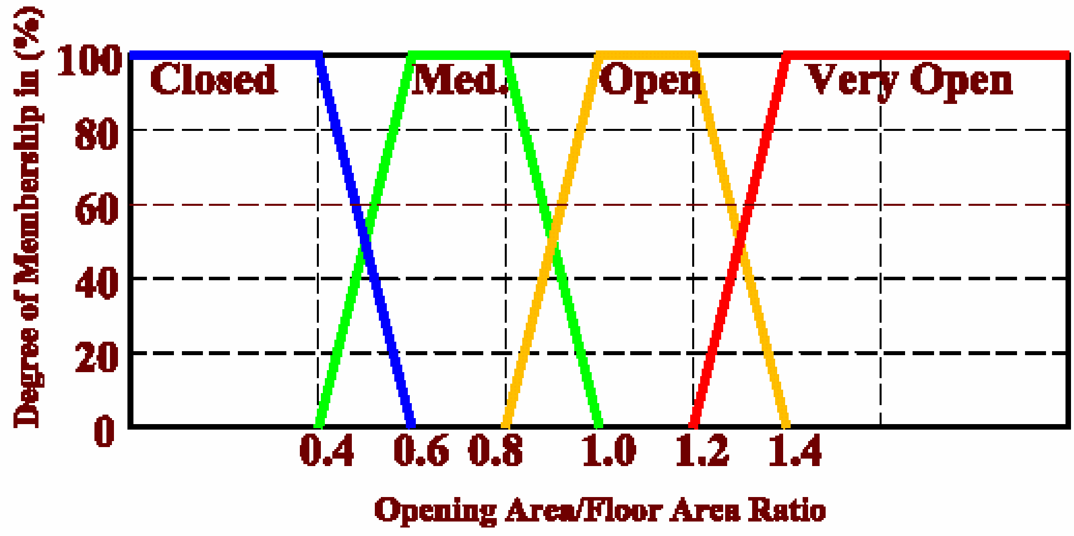


Fig. 1: Membership functions associated with the opening of the facade are referred to as "closed", "medium", "open" and "very open"

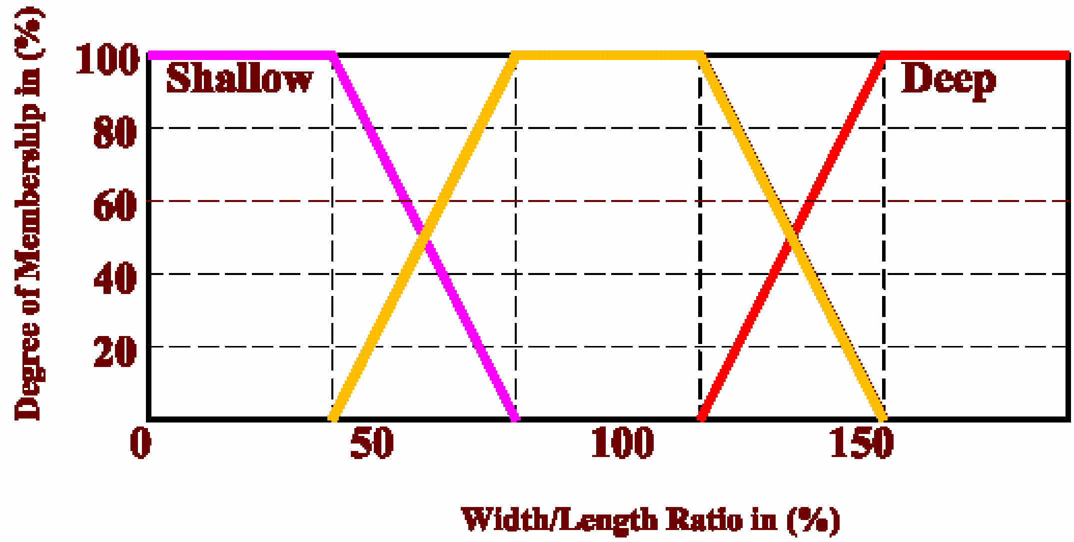


Fig. 2: Membership functions associated with the geometry of the space are referred to as "shallow", "medium" and "deep

Each value of system input will belong to at least one fuzzy set and very likely more than one fuzzy set. This is possible because during construction the adjacent fuzzy sets are made to overlap. A rule of thumb is to ensure that the sets overlap by approximately 25 percent. This is the foundation of the technique of Fuzzy Logic.

For example in figure 1 an opening value as indicated of 45 % is seen to be both a member of the "medium" and the "closed" sets. The determination of the system outputs (average daylight factor) follows from the evaluation of a set of predefined rules.

The strength of a rule is derived from the corresponding degrees of membership of the system inputs. Since an input can be member of multiple fuzzy sets, then different rules involving these sets can be applied.

The higher degrees of membership result in corresponding rules which have more strength in the final evaluation process.

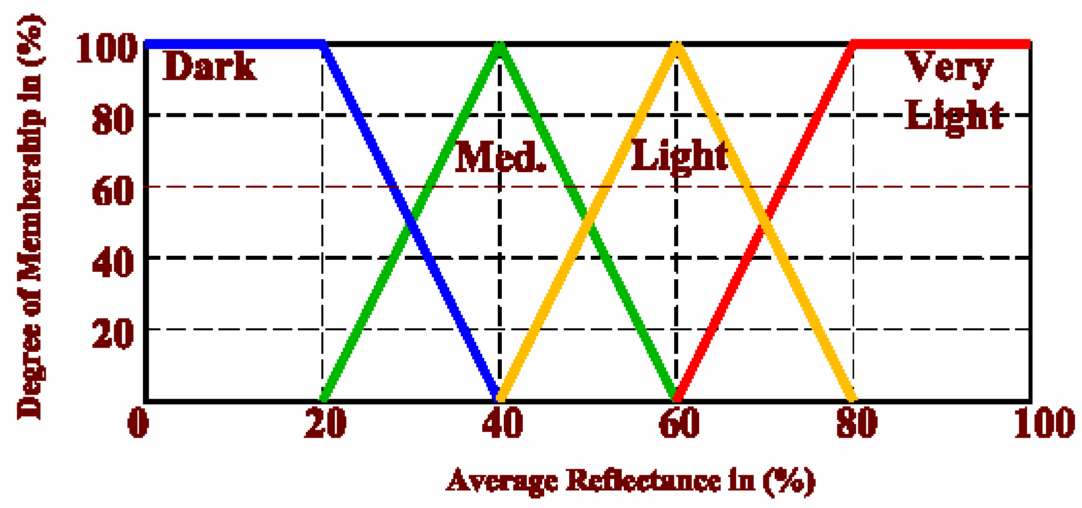


Fig. 3: Membership functions associated with the reflectance of the inner walls are "dark", "medium ","light" and "very light"

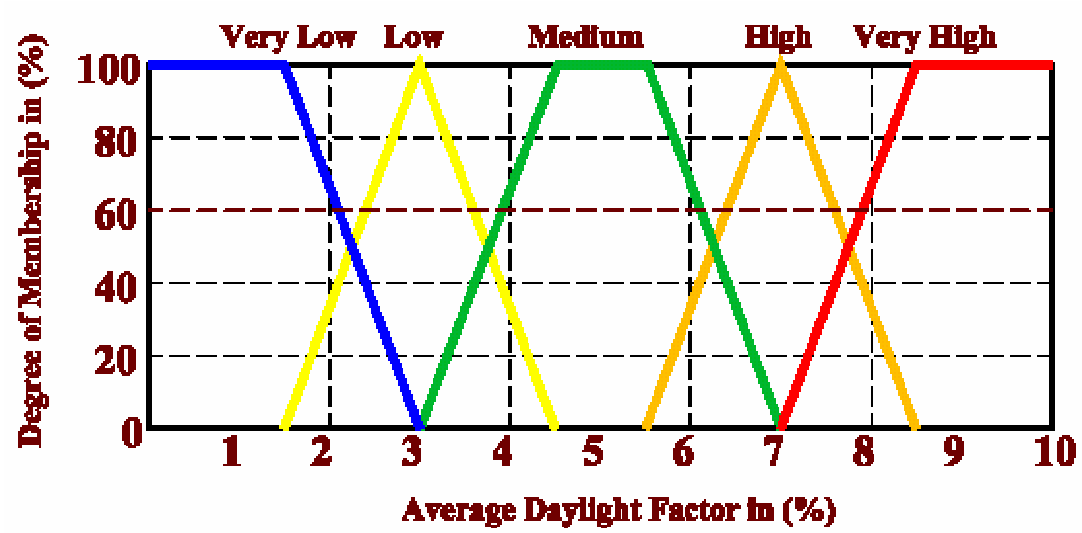


Fig. 4: Output membership functions associated with the average daylight factor are "very low", "low", "medium", "high" and "very high"

The rule base is a set of rules of the ***If-Then*** form. The ***If*** *portion* of a rule refers to the degree of membership in one of the fuzzy sets. The Then portion refers to the consequence, or the associated system output fuzzy set. For example, one rule could be stated :

***If*** (dark & deep & closed) ***Then*** (low average daylight factor)

The rules must be constructed for each system and must rely on the experience of the developer. The total number of rules is the product of the number of fuzzy sets characterizing the system. In other words, the number of rules equals all possible permutations of categorized system inputs. Here there are four sets associated with the reflectance of the inner walls, three with the geometry of the space, and four with the opening of the facades. The total number of rules that completely define the set then is 4 x 3 x 4 = 48.

It is easy to see how the number of rules rapidly expands with each system input and related fuzzy sets. The strength of a rule is the value of its least true antecedent, or ***If*** portion, which is simply the degree of membership of each system input in the corresponding fuzzy set(s). More than one rule can lead to the same consequence. In this case, the rule with the highest strength is used.

## 6. SYSTEM OUTPUTS

The system outputs are also defined by membership functions similar to the inputs. The sets for the present example are given in figure 4.

The output membership functions aid in determining a final value of the system output. The process is essentially the inverse of the evaluation of the degrees of membership. The methodology employed is referred to as the centre-of-gravity method in which the area of all applicable output sets, limited in height by the applied rule strength, are evaluated and a weighted mean value of the output is calculated.

Numerous analyses have been completed to date using Matlab Fuzzy Tool Box [9]. The following case study is presented in order to demonstrate the accuracy of the proposed calculation procedure and give the readers a direct reference for future use.

From the several calculation procedures considered for validation purposes the Superlite 2.0 computer program was selected. Superlite 2.0 program developed at Lawrence Berkeley Laboratory is well documented, has undergone extensive testing and its daylighting features have been compared favourably to a series of physical model measurements.

External conditions were then established as criteria for superlite 2.0 daylighting analysis: Overcast sky condition without any external obstruction. A standard side-lit office was used as a test room. The procedure of calculation using both Superlite 2.0 and Matlab Fuzzy Tool Box was repeated for three different situation according to the parameters described in previous section, i.e. geometry, average reflectance of the interior surfaces and opening ratio.

The effect of each parameter is evaluated individually and the results are presented in figures 5 to 7. It can be observed that results are within +-5% of Superlite 2.0 results, which suggests a good correlation between the proposed procedure and Superlite 2.0, considering the predefined external conditions. However, it should be emphasized that much work remains to be completed. Obviously the presented Fuzzy sets are simply simplified sets to a complex phenomenon, similar efforts and additional test have to be made to further develop the system. It is suggested at this point that external obstruction, orientation and sky condition dependent systems may be constructed.

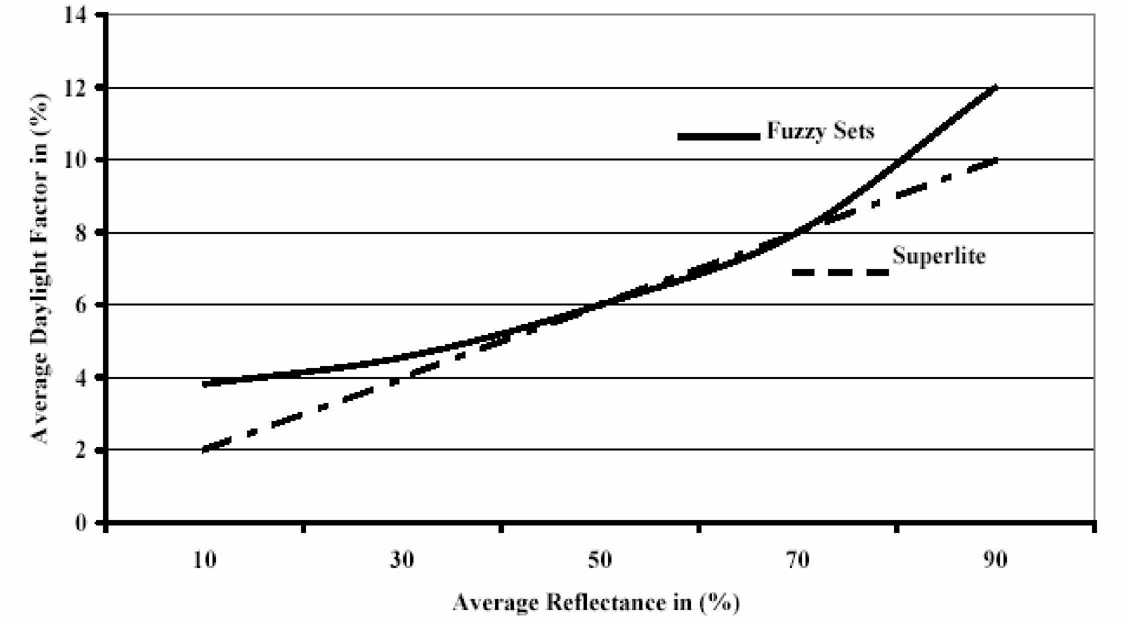


Fig. 5: Average daylight factor as a function of the reflectance of the inner walls

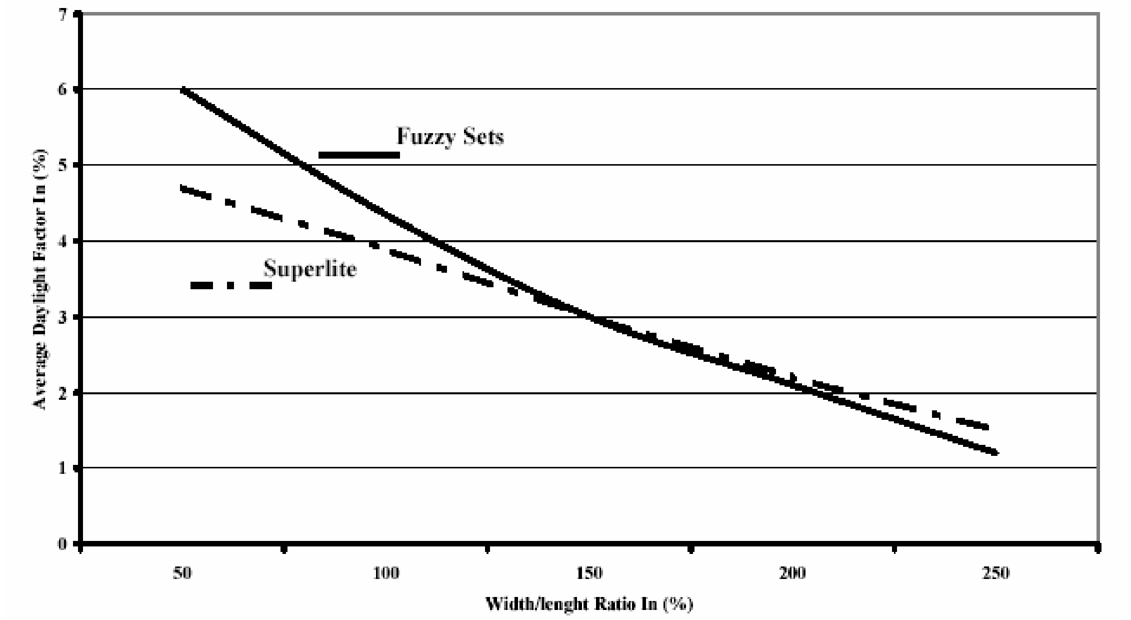


Fig. 6: Average daylight factor as a function of the geometry of the space

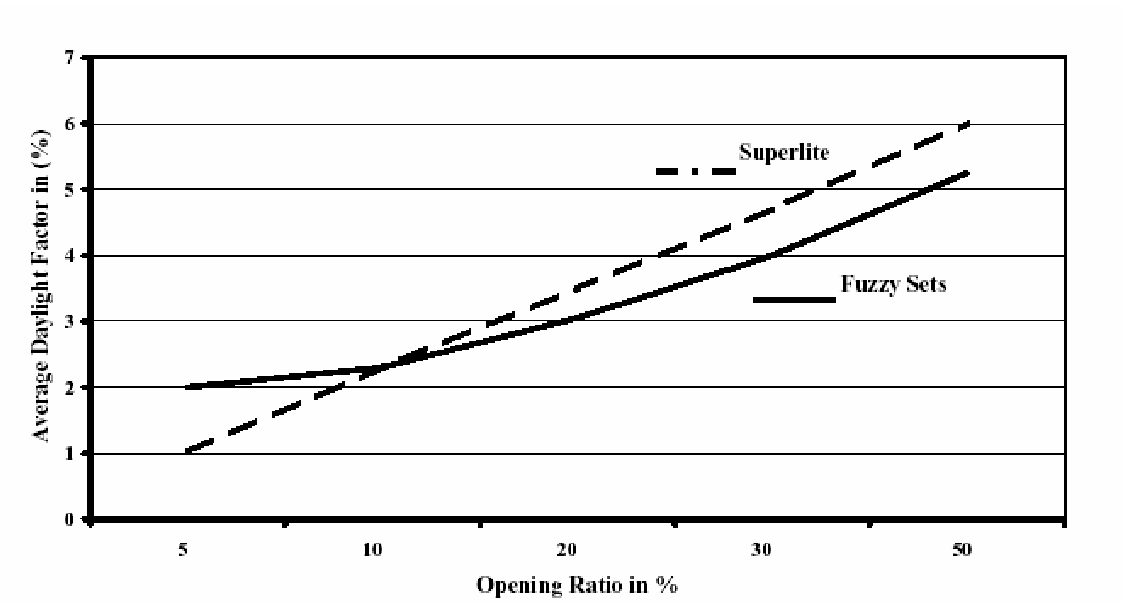


Fig. 7: Average daylight factor as a function of the opening of the space façade

## 7. CONCLUSION

The use of a Fuzzy system for the evaluation of average daylight factor has been demonstrated. It is also suggested that the experience of the developer is very important. Careful construction of the membership functions as well as the rule base is necessary. This decision-making method is very flexible and could be applied in a variety of design situations. Other situations for which fuzzy systems could be developed include glare appreciation artificial lighting control and optimization.

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