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Application of Fuzzy Logic in Interior Daylight Evaluation

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ABSTRACT

In the present day electricity consumption in indoor and outdoor lighting systems has continuously increased. Daylight as a primary source of illumination may be used as a sustainable development concept as the day lit area has very promising energy-saving opportunities. A Day lighting system is comprised of daylight apertures such as windows and skylights and different shading devices to control direct sunlight and glare.For getting the maximum benefit of daylight and to avoid obstructions, proper planning and layout of buildings is necessary. Artificial lighting may have to be provided when the level of illumination falls below the recommended value. Specifically, methods developed by the Indian standards have been used by Architects for years. The result is distributed in qualitative form for different distance from the location of windows. However in day lighting calculation it is very unsure to calculate that, whether a percentage of certain daylight factors are considered to be properly lighted, dark or dull? Traditionally there is a method to define a threshold over which an average daylight factor is considered a member of the bright set and under which it is not. Fuzzy Logic allows one to speak of a certain percentage of daylight factors is both a member of the bright set and the medium set, and possibly even the dark set. This paper addresses the Application of Fuzzy Logic in Interior Daylight Evaluation to control direct sunlight and glare. Besides, the design principles and strategies to obtain a window dimension for a given daylight factor has been discussed. For functional influence of the Building in warm humid climate of Coastal Odessa (Average latitude 21^0 North), a literature review about day lighting availability has been done. Then, the experimental set up has been described. For sufficient day lighting the calculation of solar radiation and position of windows have been worked out and graphically represented with classic and fuzzy models. Other possible design applications are suggested.

Introduction

Daylight is a part of architecture, in both its historical, theoretical, and technical conception, with a unique capacity to inspire people and to illuminate the designed interior space. During the principal hours of daylight, there is almost always enough light available from the sun and sky to provide illumination for most human visual tasks. Daylight or Natural Light describes all direct, diffuse and reflected light from the sun in the daytime. From the environmental perspective, the definition of day lighting also includes the inherent ability to turnoff electric lighting when not needed in the daytime.

Therefore proper location and dimension of the window is necessary to provide adequate daylight in building. However in day lighting calculation it is very unsure to calculate that, whether a percentage of certain daylight factor (DF) is considered to be properly lighted, dark or dull? In this case the Application of Fuzzy Logic will help to distinguish fuzzy models and classic models and help the Architects in design decision making process.

Fuzzy Control

Fuzzy logic is a computational paradigm originally developed in the early 1960's and represents a natural, continuous logic patterned after the approximate reasoning of human beings. It allows for partial truths and multivalve truths, and is therefore especially advantageous for problems that cannot be easily represented by mathematical modeling because data is either unavailable, incomplete, or the process is too complex. The real-world language used in fuzzy control enables Architects to incorporate ambiguous, approximate human logic into computers and technical applications.

Application of Fuzzy logic in architectural day lighting

In architectural design the provision of daylight is an important component. The natural phenomenon chosen here to demonstrate this method is that of the interior day lighting estimation. Several graphical methods have been developed and used over the years to aid in the prediction of the interior daylight calculation. Specifically, methods developed by the Indian standards have been used by Architects for years. However in day lighting calculation it is very difficult to calculate the distribution of daylight in a room.

Fuzzy Logic is a simple yet very powerful problem solving technique with extensive condition, the orientation of the facades, the day lighting systems, and even the surrounding environment are crucial in architectural design. However, the purpose here is to demonstrate the applicability. It is currently used in the fields of engineering and architecture. 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. 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.

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Traditionally we must define a threshold over which an average daylight factor is considered a member of the bright set and under which it is not. Fuzzy Logic allows one to speak of a certain percentage of daylight factors 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 as a member of the medium set than it is 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 statistical methods and analytic methods. In some cases, decision trees or flow charts have been developed. However, these are based on traditional logic.

System Inputs and Fuzzy Sets

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. Within the context of the current example of interior daylight estimation, general terms associated with Fuzzy Logic has been 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 this paper the system output is the average daylight factor. System inputs to be used in this case are the values of openness, location of the openings and size of the room. There are other physical variables that designer may consider important in the lighting design of his project.

Difference between fuzzy control and conventional control

Fuzzy logic is a computational paradigm originally developed in the early 1960's and represents a natural, continuous logic patterned after the approximate reasoning of human beings. It allows for partial truths and is therefore especially advantageous for problems that cannot be easily represented by mathematical modeling because data is either unavailable, incomplete, or the process is too complex. The real-world language used in fuzzy control enables Architects to incorporate ambiguous, approximate human logic into computers and technical applications. Using linguistic modeling, as opposed to mathematical modeling, greatly simplifies system design and modification.

There is a fundamental difference between fuzzy control and conventional control: conventional control starts with a mathematical model of the process and controllers are designed based on the model; fuzzy control, on the other hand, starts with heuristics and human expertise and controllers are designed by synthesizing these rules.

The recommended daylight factors for typical residential building interiors of warm humid climate of Coastal Odisha are given in Table 1. In this table, 1 percent DF is taken as equivalent to 80 lux. Thus 2.5 percent DF will be equal to 200 lux.

Sun light in different time of the day and location of window

The intensity of the sun light varies in different time of the day as per the position of the sun with reference to the building and location of the window. This has been graphically shown in fig. 1

The quantity of light admitted depends in general terms on the size of the window or windows in relation to the area of the room lit, and the depth inside the room to which useful light will penetrate. It also depends on the height of the head of windows above floor level. Working Plane is a horizontal plane at a level at which work will normally be done. This is generally assumed as 75cm from the floor in dwellings. Height of the sills between 30 and 60cm above the working plane may give more efficient distribution of light.

The value of the current surface reflectance factor is categorized into one of four fuzzy sets: dark, medium, light and very light. Similarly, the position of the window is described as window near the floor, window near the ceiling and window at the working plane.

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 system outputs will be obtained. This is the critical process of tuning, or calibrating, the system. The fuzzy sets are quantitatively defined by membership functions. 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.

Methodology

The daylight factor calculation based on the assumption that, ignoring direct sunlight, natural light reaches a point inside a building as Sky component (SC), directly from the sky, through an opening such as window. Externally Reflected Component (ERC), reflected from the ground and other buildings, and Internally Reflected Component from internally reflected surface. The daylight factor is given as a percentage and is simply the sum of each of these three components. The sky component is determined by using daylight protractors (fig.2). The first one used in section, determines the SC for an infinitely long window. The average altitude angle of the sky has to be considered. This is simply the bisector of the top and bottom angles going through the geometric centre of the window. This value has to be corrected using the second protractor in plan. This is because most windows are not infinitely long. The lay out the protractor in plan should be such that the centre point is exactly on the focal point and the main axis is parallel to the window. Determine the correction factor for both sides of the window. The Daylight Factor (DF) is a measure of natural daylight in a space. It quantifies the amount of light at a given space relative to the simultaneous amount of daylight available outside. A DF of 2 percent would mean that the indoor daylight is 2 percent of the available outside daylight, i.e. if the outside light is 8000lux, the indoor daylight would be 160 Lux. A DF of 1 percent would provide a low level of light. A DF of 2 per cent will be an "average" daylit space. A DF of 4 per cent will be perceived as a bright daylit space.

The light reaching the point after reflecting from an obstruction outside the window is the external reflected component (ERC). The internal reflected component (IRC) varies from point to point in a room depending on the interior finish. The IRC value is maximum at the centre of the room and decreases on either side of the centre. Internal reflection is due to the floor, wall and ceiling. The portion of the light reflected is called the reflection factor. Light surfaces have high reflection factors. For white surfaces, the factor is 70 to 80 percent and dark surfaces have a low factor of the order of 10 to 20 per cent. Therefore, the reflectance factors of the room finishes should be known to arrive at the IRC. Generally it can be assumed that for normal finishes, say around 40% reflection factor, and for normal window sizes, say about 20% of floor area, the internal reflection factor is 0.7 per cent. This value can be safely assumed for most of the calculations and must be added to the sky component and ERC.

The intensity of daylight received on a surface inside a building from an overcast sky can be calculated using the 'daylight factor' method. The daylight factor has been calculated by using the D.F. method for latitude 21^0 North (Fig3). The result and the changing quality of light have been given in Table 2.

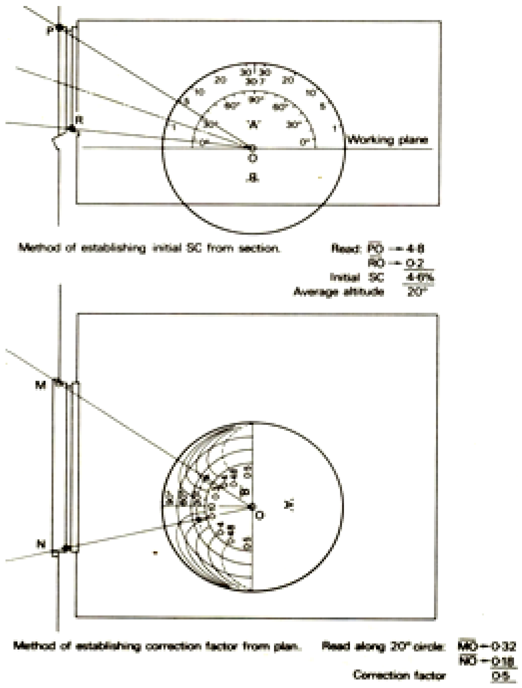

Fig 1 & 2 Daylight Protractors

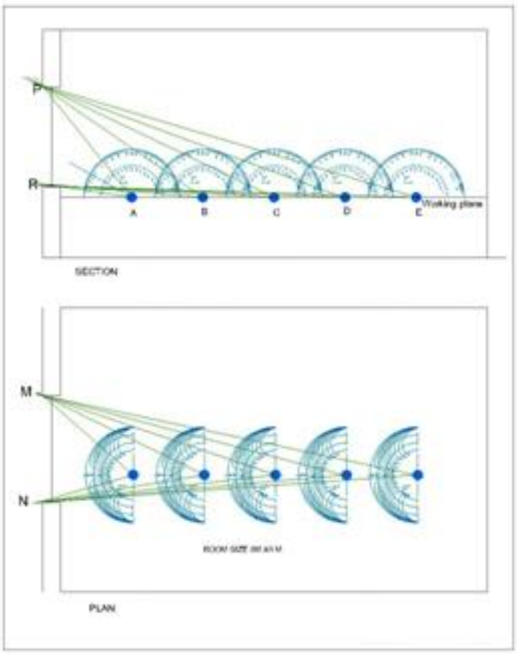

Fig 3. Use of Daylight Protectors for calculation of SC, ERC and IRC

Fuzzy logic in interior daylight evaluation

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. The effect of each parameter is evaluated individually and the results are presented in figures 4 to 11.

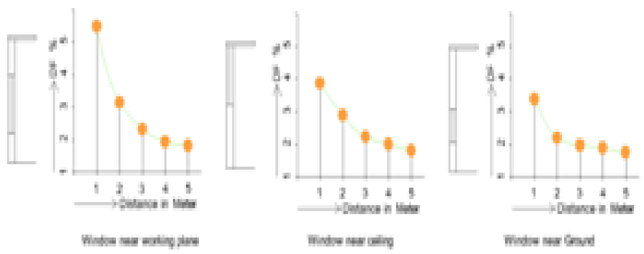

Fig 4. Day light gradient inside the room at difference distance (Classic Model)

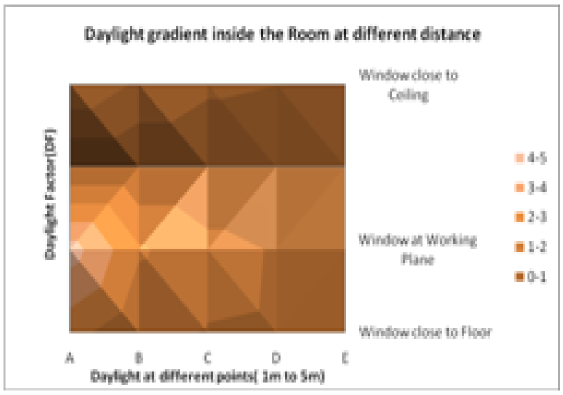

Fig 5. Day light gradient inside the room at different distance (Fuzzy Model)

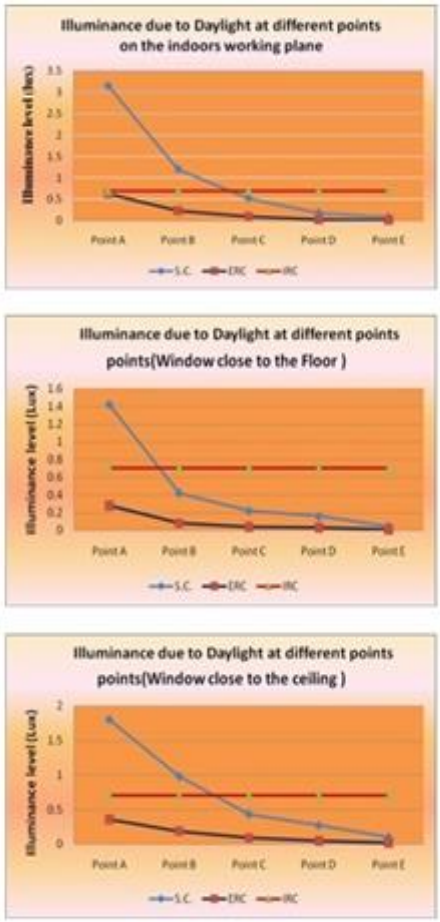

Fig 6-8. Illumination due Day light gradient inside the room at difference distance (Classic Model)

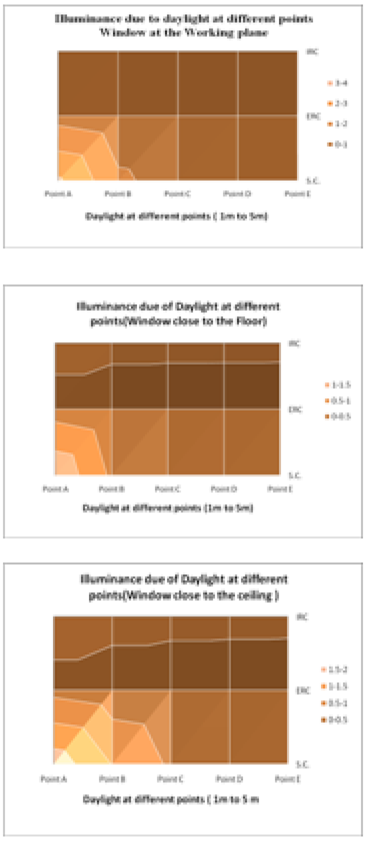

Fig 9-11. Illumination due Day light gradient inside the room at difference distance (Fuzzy Model)

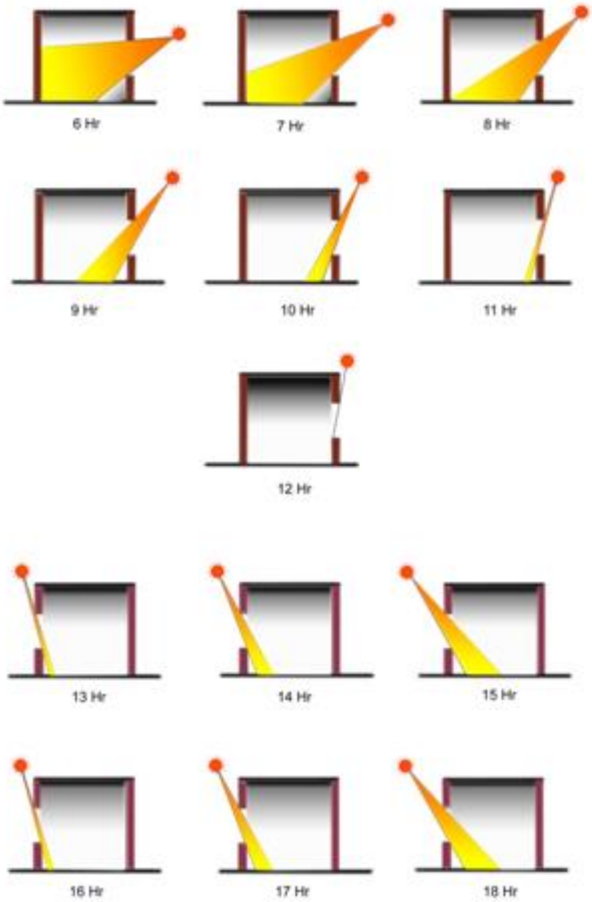

Fig 12. Sun light from the eastern / western sky from 6 hr to 18 hr on 15 April (Latitude 21^0 N)

Fuzzy model for solar radiation

The input parameters of the fuzzy model were hour, azimuth and altitude angle. Output is the direct solar radiation on horizontal and vertical surfaces.

It has been pointed out earlier that hourly irradiation data leads to more accurate modelling of solar energy processes. In this paper, the correlation between hourly and monthly solar radiation has been examined.

Skylight is a non-uniform extended light source. Its intensity and spatial distribution vary as a function of prevailing sky conditions. In addition to direct sunlight, sky luminance angular distribution is the necessary and sufficient information required for calculating daylight penetration into building environment. In those methods monthly data for summer has been analysed.

Basically, Fuzzy Logic is a multi-valued logic that allows intermediate values to be defined between conventional evaluations such as true/false, yes/no, high/low etc. The corresponding fuzzy set with a smooth membership function is shown in figure. The curve defines the transition from lighted, dark or dull.

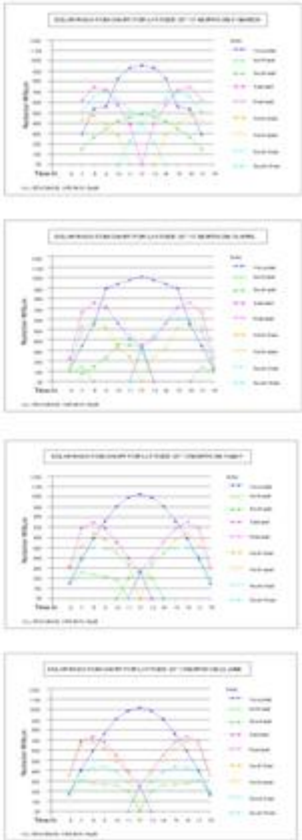

Fig 13-16. Solar Radiation (Classic Model)

Daylight Availability

Odisha has year-round access to sufficient daylight for lighting residential buildings. The average illumination level under overcast skies at latitude of 21° N is 8000 lux. This is about 20 times more illumination than that required to perform average indoor tasks.

All building orientations have daylighting potential. It is a matter of using the appropriate techniques to take advantage of daylight. Shown below is an example of monthly solar radiation in Coastal Odisha. This clearly shows the difference between the amounts of incident solar radiation in differerent orientation during the summer months.

Internal optical and thermal comfort is closely related factors, they depend on solar radiation availability and buildings geometry (the arrangement of the apertures in the envelope with regard to the room sizes), are essentially impacted by the shadings movement. The fuzzy controller contains the control rules directly derived from the observed process. The fuzzy system is able to control the inside illuminance in correlation with the available solar radiation as shown in fig. 11 to 18.

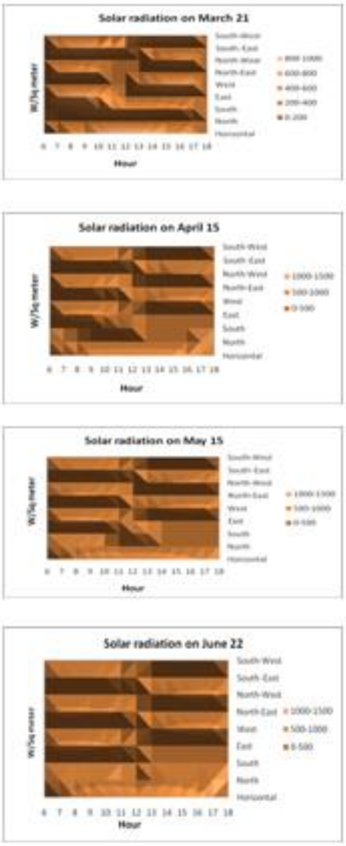

Fig 17-20. Solar Radiation (Fuzzy Model)

Daylight factor is simply in concept and in definition but its availabiliy relate to the geometry of the room to the sky. Thus the sky luminance distribution in relative units must be known or assumed such that the interior space can be related to that part of the sky that will particulaly influence the inteiror space. The simplest sky from the point of view of daylight factor is one with a uniform distribution. Since sky luminance is independent of position, the daylight factor will only be related to the area of sky as seen from the space. The daylight factor can be used not only as an indication by itself of daylight acceptability, but also as a means of determining absolute illuminance levels. In this case knowledge of the ralative sky luminance distribution is not enough; the exterior horizontal illuminance resulting from this luminance distribution must be known.

Result and Discussion

In recent years, the control technology has been well developed and has become one of the most successful tools in the industry. However, due to above mentioned aspects, traditional control systems, based on mathematical models, have shown their limits as daylighting energy-management controls. Taking into account the random pattern of potentially available daylight and rapid change of its characteristics, fuzzy control has proved to be a more convenient solution.

Daylighting has a very promising energy-saving potential and became an attractive alternative to conventional indoor electric lighting systems. Classic control systems, present some difficulties to adjust their performances to the rapid changes in daylight depending on season, location or latitude, and cloudiness. Taking into account these aspects, fuzzy control could be a better solution in implementation of daylighting, and it's an issue that cannot be easily represented by mathematical modeling because data is unavailable, incomplete, or too complex.

The most useful method of the fuzzylogic is fuzzy mean method. This can be used for interior daylight evaluation in different climatic conditions. The daylighted building should need only minimal electric lighting during daylight hours. Lighting controls can be used to dim or turn off electric lighting when bright sun makes the electric lighting unnecessary, and this can result in substantial savings, due to the reductions in both power demand and energy use.

In recent years, the control technology has been well developed and has become one of the most successful tools in the industry. However, due to above mentioned aspects, traditional control systems, based on mathematical models, have shown their limits as daylighting evaluation. Taking into account the random pattern of potentially available daylight and rapid change of its characteristics, fuzzy control has proved to be a more convenient solution.

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps membership's functions and values (Sky component, external reflected component and internal reflected component). The output stage consists of daylighting Factor (DF). The processing stage invokes each appropriate rule and generates a result for each, then combines the results. Finally, the output stage converts the combined result back into a specific control output value. The application of Fuzzy model for daylighting helps to design daylit interior space and the proper location of windows. This will provide adequate daylight to interior space and save energy during daytime.

Conclusion

Fuzzy Logic is a simple yet very powerful problem solving technique with extensive Applicability in the field of architectural design. The use of a Fuzzy system for the evaluation of average daylight factor has been demonstrated. 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.

In this research, the capacity of fuzzy logic theory to be used for interior daylight evaluation has been investigated. The model has been graphically represented with classic model and fuzzy model. The comparative study model helps the designer in daylighting calculation. The fuzzy logic model may require more parameters to be taken under consideration for better result and follow the same methodology for other regions and climate conditions.

The available exterior daylighting environments effectively influence the inteiror daylight conditions. Besides illuminance distribution in a particular room is affected by the state of the sky and the position of the sun in the sky. However the actual sky conditions vary considerably from the idealized overcast and clear sky models. This paper concludes that, the limitations of calculating Daylight factor by using daylight protactors and illustrates the applicatin of Fuzzy Logic in actual daylight evaluation. In many cases the existing daylighting calculation method are largely inappropriate to real daylighting condions. Therefore fuzzy controllers for daylighting may be adopted for evaluation and implementation in design.

Table 1. Occupancy, D.F. Percentage& Illumination

Occupancy	D.F. Percentage	Illumination(Lux)
Bed Rm	1	100
Dining	3.75	300
Kitchen	2.5	200
Bath Room	1.25	100*
Stairs	1.25	100
Garage	0.87	70
Reading (casual)	3.75	300

Table 2. Sky Components (SC), External Reflected Component (ERC), Internal Reflected Component (IRC)

Working Plane	Window close to ceiling	Window close to Ground
Point A	Point A	Point A
S.C. = 3.15	S.C. = 1.8	S.C. = 1.42
ERC = 0.2 x 3.15= 0.63	ERC = 0.2 x 1.8 = 0.36	ERC = 0.2 x 1.42= 0.28
IRC = 0.7	IRC = 0.7	IRC = 0.7
D.F. = 3.15+ 0.63+ 0.7	D.F. = 1.8 + 0.36 + 0.7	D.F. = 1.42 + 0.28 + 0.7
= 4.48	= 2.86	= 2.4
= 358 Lux	= 229 Lux	= 192 Lux
Point B	Point B	Point B
S.C. = 1.2	S.C. = 0.98	S.C. = 0.42
ERC = 0.2 x 1.2 = 0.24	ERC = 0.2 x 0.98 = 0.19	ERC = 0.2 x 0.42 = 0.08
IRC = 0.7	IRC = 0.7	IRC = 0.7
D.F. = 1.2+ 0.24+ 0.7	D.F. = 0.98 + 0.19 + 0.7	D.F. = 0.42+ 0.08 + 0.7
= 2.14	= 1.87	= 1.2
= 171 Lux	= 150 Lux	= 96 Lux
Point C	Point C	Point C
S.C. = 0.52	S.C. = 0.43	S.C. = 0.22
ERC = 0.2 x 0.52= 0.10	ERC = 0.2 x 0.43 = 0.09	ERC = 0.2 x 0.22= 0.04
IRC = 0.7	IRC = 0.7	IRC = 0.7
D.F. = 0.52 + 0.10 + 0.7	D.F. = 0.43 + 0.09 + 0.7	D.F. = 0.22 + 0.04 + 0.7
= 1.32	= 1.22	= 0.96
= 106 Lux	= 98 Lux	= 77Lux
Point D	Point D	Point D
S.C. = 0.19	S.C. = 0.27	S.C. = 0.16
ERC = 0.2 x 0.19= 0.04	ERC = 0.2 x 0.27 = 0.05	ERC = 0.2 x 0.16= 0.03
IRC = 0.7	IRC = 0.7	IRC = 0.7
D.F. = 0.19+ 0.04+ 0.7	D.F. = 0.27+ 0.05 + 0.7	D.F. = 0.16 + 0.03 + 0.7
= 0.93	= 1.02	= 0.89
= 74 Lux	= 82Lux	= 71Lux
Point E	Point E	Point E
S.C. = 0.09	S.C. = 0.10	S.C. = 0.045
ERC = 0.2 x 0.09= 0.02	ERC = 0.2 x 0.10 = 0.02	ERC = 0.2 x 0.045= 0.009
IRC = 0.7	IRC = 0.7	IRC = 0.7
D.F. = 0.09 + 0.02 + 0.7	D.F. = 0.10+ 0.02+ 0.7	D.F. = 0.045 + 0.009 + 0.7
= 0.81	= 0.82	= 0.754
= 65Lux	= 66 Lux	= 60Lux

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