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Fuzzy Logic: A New Method for Energy Efficient Green Building Evaluation

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Abstract:
A green building is a sustainable building that is designed, constructed, operated and utilized in an ecologically efficient manner. This entails the achievement of basic requirements as keeping a healthy and comfort environment, minimizing energy usage, optimizing using resources (e.g. water, gas, electricity, etc.) and reducing all impacts to the environment.
In this research, an integrated approach has been proposed to ensure that green building design is treated as a unity and holistic system rather than being a collection of stand-alone systems. Emphasis is given to the study of the basic parameters during conceptual design phase that ensures a green building which controls energy expenditure and hence enables high building efficiency.
Proper site selection, passive design strategies for maximum energy saving, optimum material selection, efficient resources usage, health and safety considerations, environmental quality and recycling of waste are some of the basic items to affect directly buildings energy efficiency.
Fuzzy logic, as being a means that gives possibility to embrace and optimize multiple parameters in the process of decision making, has been implemented. Consequently, a computer program has been, herein, put forward to simplify design evaluation by architects using fuzzy ranking design items relative to standard green goal.

Keywords: Green Buildings, Fuzzy Logic, Energy Efficient Buildings, Conceptual Design, Decision Making.

1. Introduction:

Buildings are the largest energy consuming sector in the world and account for over one –third of total final energy consumption and an equally important source of carbon dioxide emissions [1].
Reducing energy use in buildings is of the utmost important. Most studies towards buildings with the least impact on the environment have energy as their point of focus. Buildings demand for energy is direct and indirect. Directly they require energy for their construction and operation and indirectly through the production of the materials they are made of [2].
The green building revolution is a movement in buildings to become sustainable. It regards many disciplines including energy conservation and the need to rely on non-renewable resources in buildings.
In this research we are concerned with the design of green buildings regarding the operating energy in buildings. Consumption of energy during the operation of a building results from the improper designs produced by architects who ignore energy demands during this important phase in the life-cycle of the building. Green buildings can offer a 30 percent energy savings [3].Hence, through a better design of a green building externally and internally we can reduce the building demand for energy during its operation.
It is well known that during the preliminary design stage architects produce a number of alternatives for their design. Choosing an alternative regarding energy aspect is not easy and an inconvenient design can cause environmental consequences for decades after the building is built.
Many elements are used in our initial designs that are responsible for energy consumption in buildings including the way of lighting in the building, the way of ventilation, the finishes and materials used in construction, the way of insulation, the building envelope and other different elements. All of these elements must be totally considered in the preliminary design stages to achieve energy efficient green designs.
A computer program using mat-lab software will be introduced herein as an easy way for evaluating different alternatives .It is based on the use of fuzzy logic theory which can deal with any number of parameters that have a direct effect on energy consumption. It is a new measuring tool for architects that depend on verbal evaluation for every parameter which is thereafter be translated mathematically and gives numerical evaluation for the different design alternatives [4].

2. Problems Facing Green Design with Respect to Energy

Many problems face green designers in the preliminary design stages when they begin to take decisions to choose an optimal alternative within a set of alternatives. These problems are illustrated in figure 1.

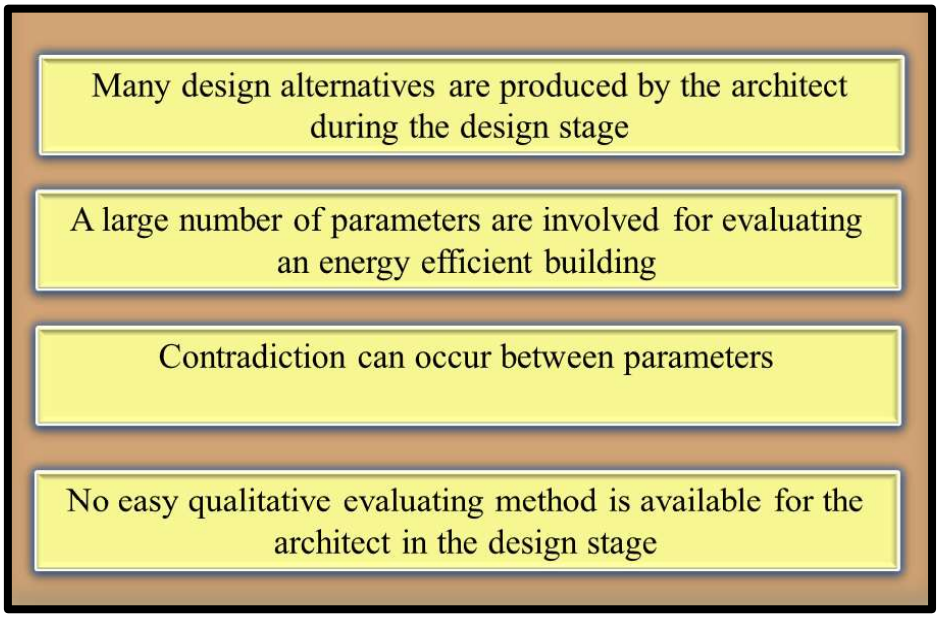

Figure (1): Problems facing green designers

3. Research Objective

This research is an endeavor towards evaluating, rationalizing and recommending the most optimum architectural solutions for most efficient utilization of energy in green buildings.

A novel method for evaluating the different alternatives produced by the green designer, regarding energy, is discussed. All the parameters regarding energy will be assessed in order to be an input data to be used with the MATLAB computer program for evaluating different alternatives. This will help architects to reach the optimal alternative in reference to energy efficiency in buildings and thus helping towards sustainability and better improvement for our environment.

4. Research Methodology

In this research a special procedure has been followed as shown in figure 2. The parameters constituting the architecture design of green buildings from energy point of view have been firstly assigned. Based on basic requirements of a green building the parameters are ranked. A tailored computer program has been put forward adopting Fuzzy logic theory in order to attain an optimum energy efficient alternative.

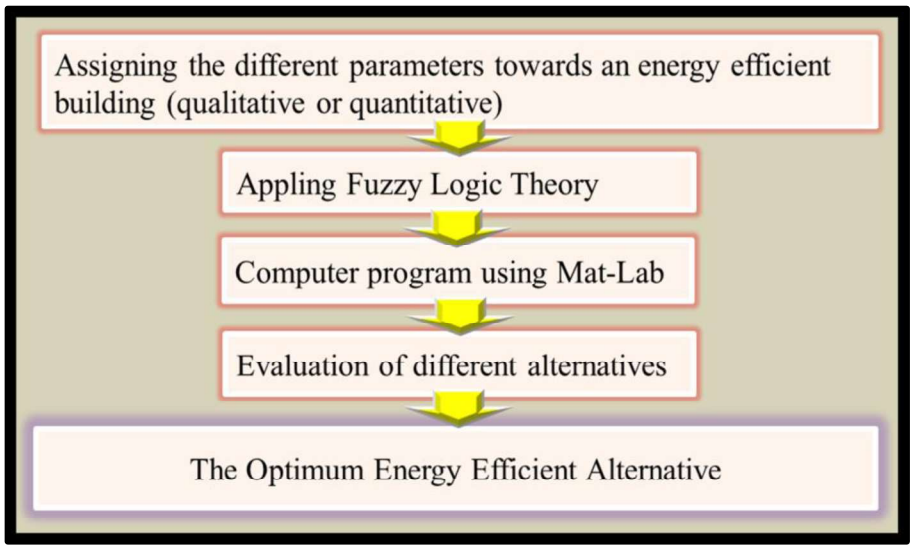

Figure (2): Applied methodology

5. Factors Affecting Energy Consumption in Buildings:

In order to understand these factors our approach will focus on minimizing the consumption of non-renewable energy resources and relying on alternative renewable resources, namely; solar and wind energies.

The main influencing factors can be classified into external factors involving the building from outside and internal factors. Items that architect must consider are shown in figure 3.

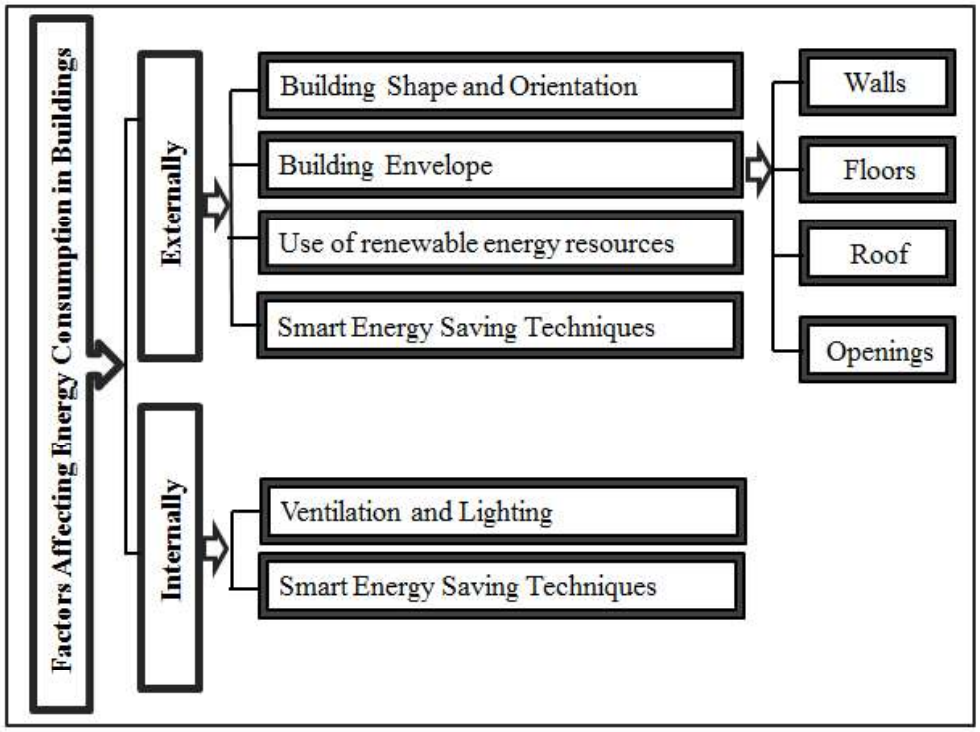

Figure (3): Factors affecting energy conservation in buildings

The proposed items will be the main parameters for the present proposed program through which design alternatives will be evaluated towards energy efficient buildings.

Successful energy efficient buildings require the use of passive solar systems as an integral part in buildings. The correct shape and orientation of the building must be considered. The building envelope with its walls, floors, roofs and openings need too to be studied. The use of overhangs and other devices together with the use of insulation and thermal mass represent also important parameters to be evaluated. Smart energy saving techniques need to be incorporated in green designs and the materials used have to be regarded according to their embodied energy and recycling after demolishing. Add to these factors, any architectural elements as sunspaces, atria, courts, wind catchers…etc., which need further consideration.

5.1. Building shape and orientation:

Building shape (the relative length, width and depth) and orientation are architectural decisions that have significant impacts on heating and cooling loads [5]. They must be considered in the preliminary design phases as a passive way which can lessen the energy demand of the building.

5.2. Building envelope:

Building envelope includes walls, floors, roof and openings. Each of these items has strong impact on energy consumption all over the lifecycle of the building.

Improving the thermal performance of building envelopes is required to reduce demands for artificial heating and cooling [6]. Designing according to passive design principles for the building envelope is required. The term passive system is applied to buildings that include, as integral parts of the building, elements that admit, absorb, store and release solar energy and thus reduce the need for auxiliary energy for comfort [7]. Figure 4 shows the different parameters incorporated in each item and can affect energy efficiency in buildings .

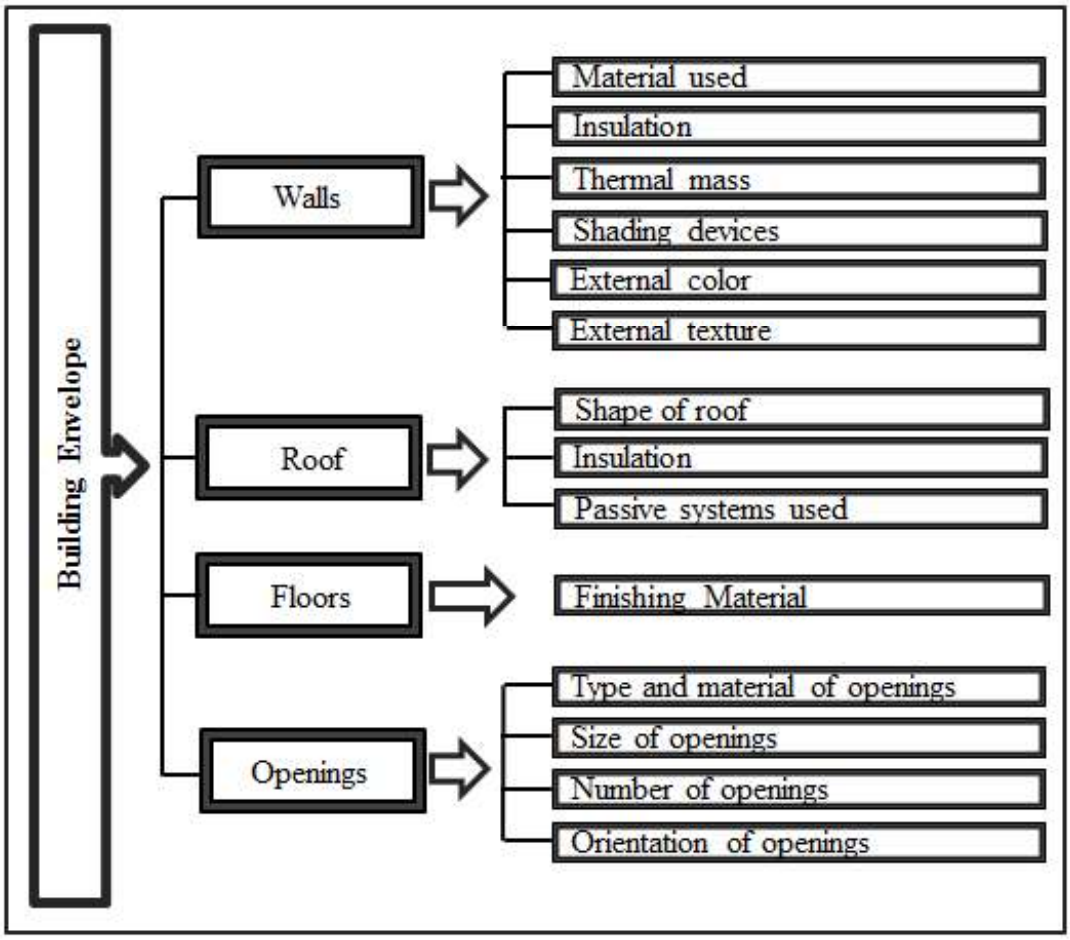

Figure (4): Components of Building Envelope

5.2.1. Building walls:

Concerning the walls of the building the material used for construction whether wood, bricks, steel or glass must be considered regarding the material embodied energy. Type of insulation used in walls, their thermal mass and the type of shadings on the walls affects building demand for energy in heating or cooling. Moreover the color of the external wall whether dark or light affects heat gain in buildings. External texture can be smooth or rough according to the type of material used and according to the amount of projections in the wall. This also has an effect on energy efficiency in buildings.

5.2.2. Building roof:

The shape of the roof whether flat, pitched, domed, vaulted,…etc. and the insulation used have an effect on the quantity of energy absorbed by the roof and thus the need for artificial heating or cooling . Also the passive systems that can be used as roof ponds and roof gardens can increase the energy efficiency of buildings.

5.2.3. Building floor:

The finishing and insulation of the floor can affect energy absorption in buildings.

5.2.4. Openings:

Solar heat gain is an order of magnitude larger per unit area through glazing than through opaque walls. Windows can make the difference between efficiency and waste [8].

5.3. Use of renewable energy resources

We have to reduce our dependence on non-renewable energy sources in buildings as they will not last forever and to use renewable ones. This is our future towards sustainability in buildings with the least impact on our environment.

We can use the sun directly (as in solar heating systems) or indirectly (as in hydroelectric power, wind power and power from biomass fuels). Solar energy can be used to produce electricity, to produce heat and for light [9].

To produce electricity, photovoltaic cells can be used. For heat, active and passive systems are incorporated in our designs. For lighting, the most common method is the window and also the presence of skylights.

5.4. Smart energy saving techniques

Smart techniques are of a great importance in our designs for an efficient energy saving building. They can be used externally as the use of smart windows or internally as the use of smart tiles in corridors especially in malls that change mechanical energy into electric energy.

5.5. Ventilation and lighting inside the building

Natural ventilation is of a great importance to maintain human comfort inside the building with less dependence on mechanical ventilation. The architect should consider the building orientation, window sizes and cross ventilation.

Moreover, a day lighting strategy must be regarded in the preliminary design stage. This depends on window

sizes, shading and space layouts [10]. Shading can be fixed or operable whether automatic or manual.
In multi-story buildings, a courtyard or atrium can allow to reach interior zones of lower floors [10].

6. Green Projects Evaluation:
LEED is a green building rating system which defines what it means for a building to be sustainable. Projects register to use the LEED rating system when finished and to receive a certification regarding the building sustainability [3].
Architects need an easy way in the preliminary design stage to evaluate the different alternatives designed as an aid finally towards a green building.
Using fuzzy logic theory in decision making suits the state in architecture. Many parameters face the architect concerning the aspect of energy. Fuzzy logic offers an easy way to evaluate these parameters verbally and thus can be used by the architect [4].
Architect by this way can evaluate by himself any number of alternatives whatever the contradictions present between them and in a qualitative manner due to the vagueness that can be present in some of the introduced parameters.

7. Fuzzy Logic Theory:
The fuzzy approach is one of the most practical ways to mimic human expertise in a realistic manner [11]. It can help in decision making for any number of parameters and can use linguistic variables, rather than quantitative variables.
Fuzzy set theory is a mathematical theory designed to model the vagueness or imprecision of human cognitive processes. It is an important branch of operation research, providing tools to quantity imprecise verbal statement [12].
The Fuzzy Logic tool was propounded in 1965, by Lotfi Zadeh [13]. Fuzzy logic [14], [15], is a mathematical tool for dealing with uncertainty. It provides a technique to deal with imprecision and information granularity. The fuzzy theory provides a mechanism for representing linguistic words such as “many,” “low,” “medium,” “often,” “few” which are always present in the architecture design process. In general, the fuzzy logic provides an inference structure that captures the imprecision of linguistic terms in statements of natural language as shown in figure 5.

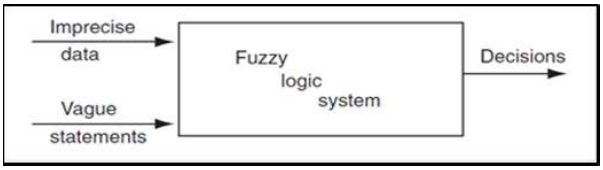

Figure (5): Fuzzy Logic System

Fuzzy logic is used in those types of problems in which the solution cannot be defined in rigid boundary either (yes or no). Fuzzy logic – set theory allows partial membership which means that it contains elements that have varying degrees of membership in the set. It is based on degrees of membership rather than usual true / false or 1/0 .
The fuzzy inference engine [16], [17], is shown in figure 6 .

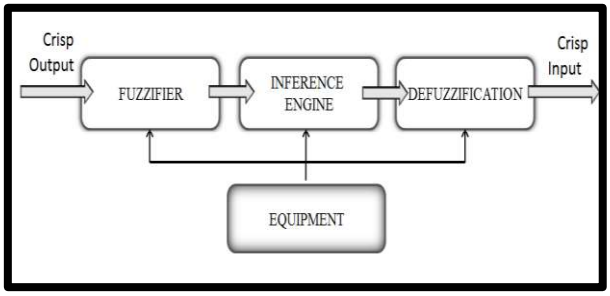

Figure (6): Fuzzy inference engine

A crisp set of input data are gathered and converted to fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This is called fuzzification. Then an inference is made based on a set of rules. The output is mapped to a crisp output using the membership functions in the defuzzification step.
Fuzzy decision making can be applied in the preliminary design stage where decisions are required.

8. Advantages of Fuzzy Logic in Preliminary Stages
There are many types of decision making: individual, multi- person, multi -objective and multi- criteria decision making.
In this paper we will deal with multi criteria decision making where there is a set of any number of parameters gathered in order to evaluate to reach a single objective regarding energy in buildings. Fuzzy logic is a suitable tool to deal with green design problems due to the following points:
1. It is easy to understand.
2. It is flexible where within a given system we can layer on more functionality without starting from scratch.
3. It deals with imprecise data.
4. It is based on natural language.
5. It can deal with multi- objective and multi- criteria decision making which suits the case in architecture.

9. Contribution of Fuzzy Logic in Green Design:
The contribution of fuzzy logic in green design can be understood through the application of different steps as in figure 6.

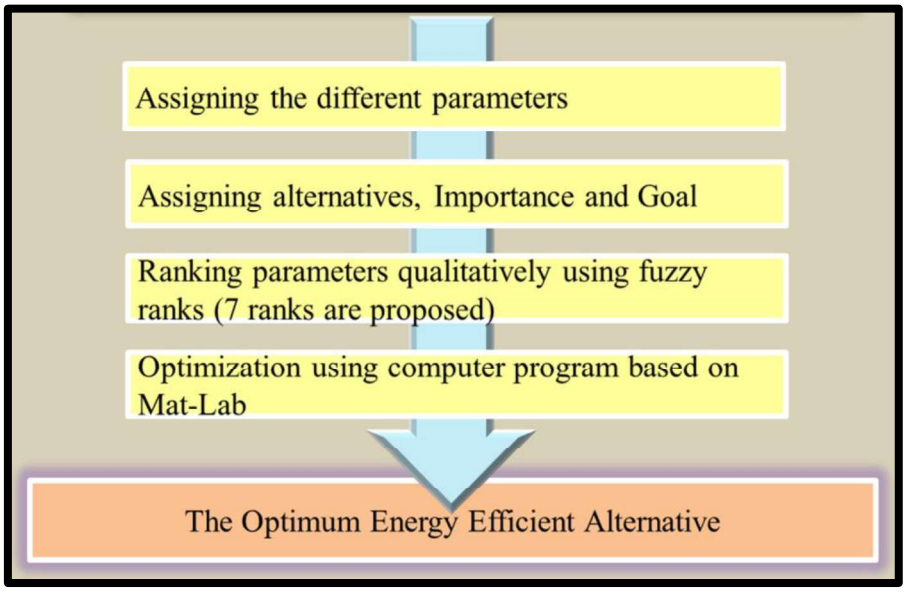

Figure (6): Contribution of fuzzy logic in green design

Many steps are involved in the decision making process. It begins with determining the set of alternatives. In this step the alternatives from which the decision has to be taken must be determined and assessed with respect to pre-determined parameters. Then evaluating alternatives where the alternatives must be evaluated regarding a certain goal so that the decision can be taken .Finally, a comparison between alternatives takes place and in this step comparison between the evaluated alternatives is done using mat lab program.

A finite set of parameters is weighted according to their importance using linguistic values where values are words or sentences [18], [19].

A decision matrix consisting of the rating of each alternative with respect to each parameter is made. Evaluation is aggregated taking into account the weights of the parameters, indicating the importance of each parameter and comparing their weight with our goal.

These steps can be summarized as follows:

1. Assigning the different parameters towards an energy efficient building (qualitative or quantitative parameters), these parameters are identified according to the designer experience and skills and by the aid of energy experts.
2. Ranking the parameters qualitatively using fuzzy ranking, seven ranks are mentioned namely: very high, high, medium high, medium, medium low, low, very low. The computer program is capable to increase the qualitative ranking of parameters beyond these seven ranks.
3. Design parameters are assigned using these previous seven ranking levels by the architect.

The fuzzy table used is shown in figure 7.

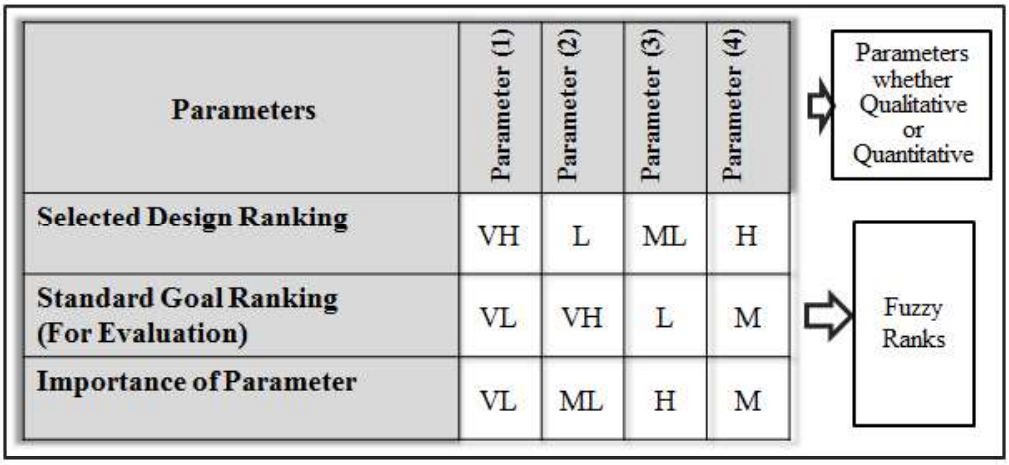

Figure (7): Fuzzy logic contribution in decision making

Optimization is applied given fuzzy ranking relative to a goal, representing the full requirements of energy efficient green buildings in the form of parameters.

In order to find the degree of approach of the selected design to the goal, a series of mathematical calculations (fuzzy analysis) must be carried which can be more and more complicated for larger problems

4. A software program based on MATLAB has been made to help architects in solving such mathematical calculations and giving finally an optimum alternative

for an energy efficient green building. A holistic evaluation of any number of alternatives can be achieved.

Figure 8 shows the different parameters that are proposed in this paper showing the way the architect can deal with using fuzzy ranks.

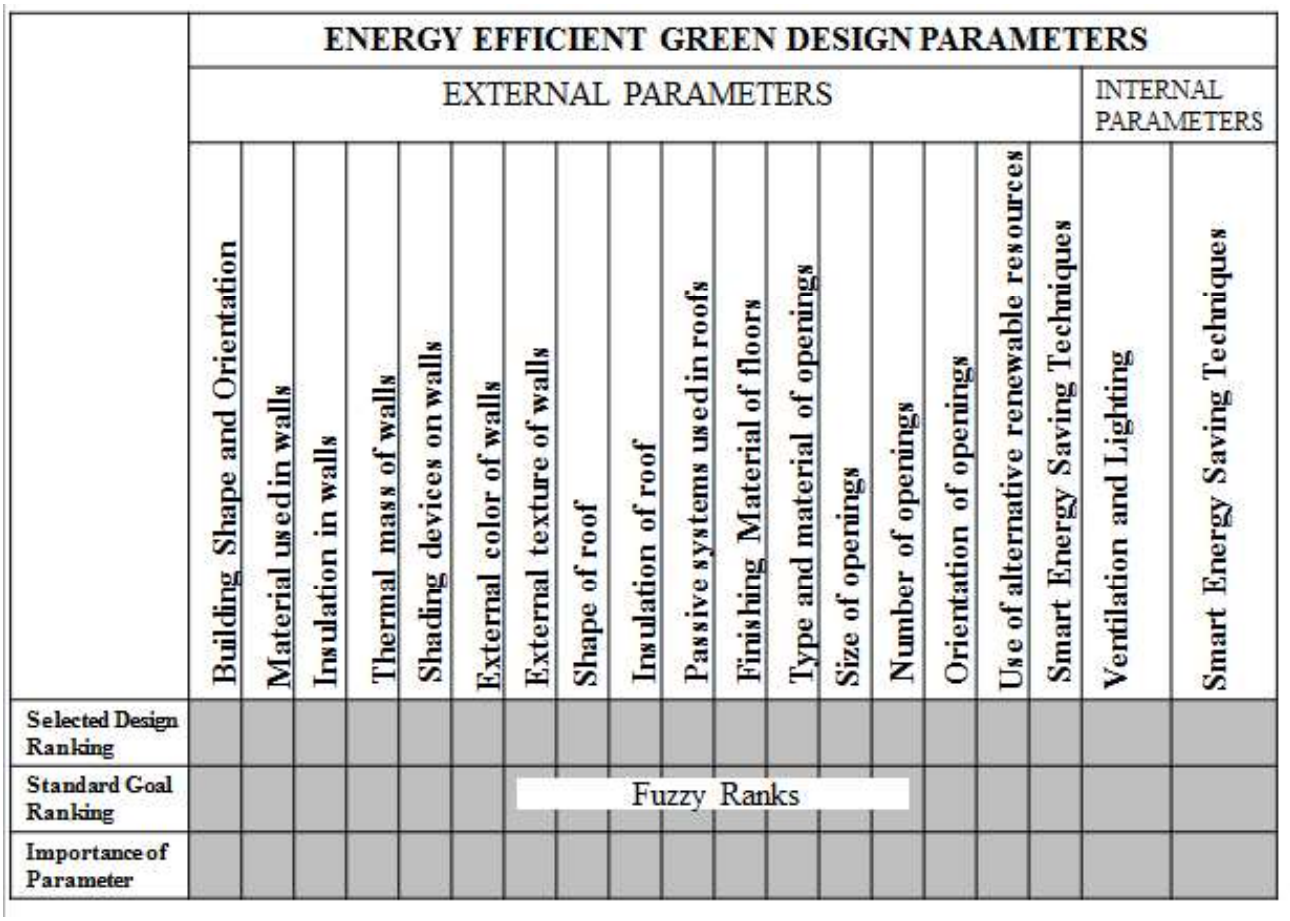

Figure (8): Fuzzy ranking for energy efficient green design parameters

10. Conclusion:

A computer program has been put forward to simplify design evaluation of architectural design problems from energy saving point of view. By fuzzy ranking design stages and identifying all parameters influencing energy saving aspects, a green building can be attained out of different proposed design alternatives that take into account all influencing parameters without ignoring any one.

11. Recommendations:

Green building design must be treated as a whole system rather than being a collection of stand-alone systems. All parameters influencing the green design process must be gathered regarding different aspects of energy, renewable resources, materials and other aspects to achieve a holistic green design that can have the least impact on our environment.

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