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ROOM AIR CONDITIONER RATING EXPERT SYSTEM FOR TROPICAL RAINFOREST ECOSYSTEMS ZONES

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ABSTRACT

This study developed a fuzzy expert system, Room Air Conditioner Rating Expert System (RACRES) for sizing residential room air conditioner. RACRES used 128 fuzzy linguistic rules 'fired' in Mamdani fuzzy inference system with four input variables; window size (m^2), roof size (m^2), exposed wall size (m^2), and internal capacity (Watt) to predict the amount of cooling required in British Thermal Units (BTUs).Using the outlined load components guidelines by ASHRAE, the Human Expert Calculations (HEC) results were compared with the RACRESBTUs predictions. The result shows that the Spearman's rho correlation coefficient of the results of human calculated values and that of the RACRES was found to be 0.838. The independent-samples t-test result also found that RACRES had statistically significantly higher level of predicted risk values (mean=4390, SEM=194.4) compared to HEC values (mean= 4289, SEM = 173.01), with $t(38) = -0.389$, $p = 0.462$. With root mean square error (RMSE) of 375.8, RACRES was shown to have a capacity of generating reliable results as can be achieved from human professionals in the field. It can mimic results from human expert manual calculations. It is simple to use and a cheap device for home builders most especially where services of professionals are expensive to hire.

Keywords: *air conditioner, sizing, room, expert system, fuzzy*

1 INTRODUCTION

A conditioner is a device used to cool a building environment. In modern society, air conditioners are commonly found in homes due to the natural demand for thermal comfort (Henry *et al.,* 2011). The air conditioning system transfers heat from a cooler low-energy reservoir to a warmer high-energy reservoir. There are several options of air conditioning, which are available for use: Air conditioning (for space or machines), split air conditioners, fan coil units in a larger system and air handling units in a larger system (United Nations Environment Programme, 2006).

The use of rules-of-thumb methods for load calculation techniques was popular. The most common rule of thumb is to use "1 ton for every 500 square feet" of floor area. The main drawback of the methods is the presumption that the building design will not make any difference. Thus the rules for a badly designed building are typically the same as for a good design (Yonas, 2014). Over time several other methods were developed and used to size air conditioning system, to mention few, Mullen and Bullard (1994) used the Newton-Raphson method for room air conditioner system modelling, SAE (2001) reported optimization of vehicle air conditioning systems using transient air conditioning performance analysis. Chin-Pao and Mang-Hui (2003) used a neural network application on fault diagnosis of a large air-conditioning system, Zhang *et al.* (2013) proposed aggregated modelling and control for air conditioning loads for demand response. Steven (2012) used load calculation spreadsheets as an alternative to relying on rules of Thumb. Radiant Time Series (RTS) was introduced but mainly intended for educational purposes (ASHRAE, 2012). Other reported methods include Z-Transfer Function, Weighting Factor Method (Mitalas, 1978)

One of the major problems in sizing air-conditioning is wrong estimates of required cooling load. This was mentioned with the use of some of the methods that require human manual efforts. However, manual cooling load calculation processes are quite difficult at ensuring accuracy (Hui and Cheng, 1998). Hence the need for methods that will reduce human involvement in the computational process. Over time, Fuzzy logic had been used extensively in many application areas to model the problem-solving ability of human experts in the mechanical engineering field and allied areas such as diagnostics, energy consumption analysis, maintenance, operation, and its control. Relatively little exists in using fuzzy logic based systems for heating, ventilation, and *air conditioning* (HVAC) conceptual design and control (Jagdev, 2006). Whereas, Fuzzy logic has the ability to imitate the logic of human thought, which is much less rigid than the calculations human and/or computer generally perform (Dan, 2003). Fuzzy logic approach to problems mimics how a person would make decisions, only much faster (Kozlowska, 2012). Fuzzy logic can deal with the vagueness intrinsic to human thinking and natural language. It deals with uncertainty and can model common sense reasoning which is very difficult for

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general systems (Ramjeet and Vijendra, 2011). Among the recent efforts using fuzzy logic applications, Nazmi *et al.,* (2009) developed a controlled fuzzy expert system to provide the conditions necessary for operating rooms. It provided more economical, comfortable, reliable and consistent controls that are feasible in a real operating room. Henry *et al.,* (2011) advanced a control strategy using a fuzzy logic controller and the technique which can save energy consumption for Air Conditioning System. Lo *et al.,* (2007) developed an intelligent technique based on a fuzzy-genetic algorithm for automatically detecting faults on the HVAC system. The present work uses fuzzy logic technique to design the Air Conditioning rating capacity for some room dimensions. The objectives are to;

- compare the BTUs ratings of human expert calculations (HEC) with that of the developed expert system rating prediction.
- minimize total dependence on scarce human experts in the study domain.

2 MATERIALS AND METHODS

2.1 Fuzzy Set Theory

Fuzzy Logic, as used in this study, consists of the heuristics rules that define the parameters of the focal problem. It consists of database, fuzzy rule base, fuzzy inference machine and defuzzification (Nagrath and Gopal, 2010). Fuzzy Logic is applicable to artificial intelligence, control engineering, and expert systems (Padhy, 2005). Fuzzy expert system is functional in a wide range of applications designed to model the problem-solving ability of a human experts (Aman *et al.,* 2011, Adeyemi *et al.,* 2013a, b). It is an appropriate approach when human evaluations and the modelling of human knowledge are needed (Kahraman, 2006).

2.2 Study Location

Abeokuta, Ogun State was selected as the study domain. Abeokuta, Ogun State, is located in a moderately hot, humid tropical climatic zone of the southwest part of Nigeria. The climatic conditions prevailing over the study area in the ecosystems were mainly those of the tropical rainforest, typified by an average annual temperature 30 ± 100C, relative humidity of 65 ± 10% and an average annual rainfall of 1500±120mm (Oguntoyinbo *et al.* 1983). There are two distinct seasons in the state namely, the rainy season which from March/April to October/November and the dry season which lasts for the rest of the year, October/November till March/April. The temperature is relatively high during the dry season with a mean temperature of around 30°C.

2.3 Architecture of the Proposed Room Air Conditioner Rating Expert System (RACRES)

The architecture of the proposed RACRES is stated below and as shown in Figure 1:

- Input sourcing is data collection via literature and field survey. Crisp value is the input factors relevant for sizing capacity of the room Air conditioner.
- Fuzzification converts the crisp value into fuzzy input value using appropriate membership function (MF).

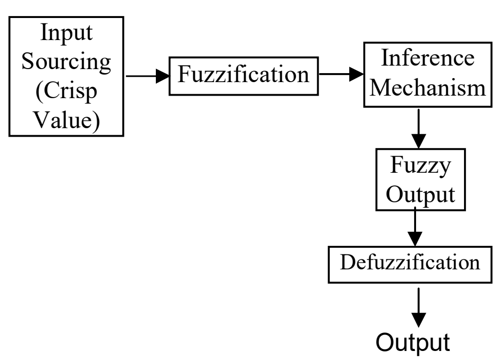

Figure 1: Architecture of the proposed RACRES.

- Inference mechanism defines 'If-Then rule'.
- Fuzzy output determines an output MF value for each active rule.
- Defuzzification calculates the final output (amount of BTUs).
- Output gives the crisp value (quantity of BTUs) required.

2.4 Development of RACRES

Four input variables were considered in this study. They are window size (m^2), roof size (m^2), exposed wall size (m^2), and internal capacity (Watt). These variables, according to ASHRAE (2001) are key contributors to right selection of air conditioner of residential rooms.

2.5 Data Collection

Trained personnel were involved in data collection following the procedures detailed by the ASHRAE load components. A total of 155residential rooms were assessed for the recording of variables. Occupancy comfort levels derived by the subjects using the assessed air conditioner capacity were measured with a questionnaire. This was achieved by using the direct method of assessing thermal comfort under operating conditions as outlined in the guidelines stated by ASHRAE (2013); the acceptability and satisfaction of the size of air conditioners in use by the occupants were directly determined from the responses of the occupants using the scales ending with the questions: "very satisfied" and "very dissatisfied." Those with positive responses were noted and the cooling capacity of the air conditioner in such room was recorded. The surveys also included diagnostic questions which allowed causes of dissatisfaction mentioned by subject(s) to be identified.

All lengths (m) were measured using the SI unit system. The wattage of all room appliances and lighting were recorded from their manufacturers' manual. Human professionals in the field of HVAC drawn from academics environment were involved in the manual calculations of the cooling capacity for the recorded variables using Excel spreadsheet. The following equations (1) to (9) as outlined in the ASHRAE load components guideline were used by human experts for their manual calculations.

Load (q) from Window Area = (GLF) A (1)
Load (q) from Ceiling and Roof Area = $U_rA(CLTD)$ (2)
Load (q) from Doors =$U_dA(CLTD)$ (3)
Load (q) from Exterior walls = $U_wA(CLTD)$ (4)
Load (q) from partitions to unconditioned space = $U_pA\Delta t$ (5)
Load (q) from Internal (people, appliances, light) = 67W per person (6)
Load (q) from infiltration = $1.2Q\Delta t$

$$Q = ACHx(roomvolume)x\frac{1000}{3600} \quad (7)$$

The total cooling load (sensible plus latent) may be estimated by applying the Latent Factor (LF).

The sensible cooling load refers to the dry bulb temperature of the building and the latent cooling load refers to the wet bulb temperature of the building.

The total cooling load = LF x total sensible load = 1.15 x $q_{rm.}$ (8)

The total design flow from the air conditioner can be estimated using equation (9)

$$Q_{wt} = \frac{1000q_{rm}}{1.2\Delta t} \quad (9)$$

This helps to reduce the ventilation rate in an existing house with high infiltration.
where
Q_{wt}= total airflow, L/s
q_{rm} = room sensible cooling load, W
1.2 = density of air times specific heat of cooling air (at sea level and at 15°C, air has a density of approximately 1.225 kg/m^3 and the specific heat of cooling air = 1.01 kJ/kg. K.
Δt =temperature difference of air entering and leaving room, K
Using 1Litres-atmosphere per seconds equivalent to 345.74 Btu per hour, the cooling capacity of each room was manually computed.

2.6 Fuzzification of variables and risk value

Fuzzification was carried out using input variables and theirmembership functions of fuzzy sets. According to Garrido and Ramos (2000), linguistic label definitions are usually established by an expert. Linguistic terms were assigned by an expert to the domain of the input variables, eachhaving three trapezoidal MFs (Figure 2). Determination of all the four input variables' intervals was derived from the same expert knowledge and was confirmed suitable when made available to independent four (4) relevant human professionals in academics environment. Trapezoidal MF used in this study has more applicability in modeling applied engineering problems (RG, 2014). It is defined by a lower limit a, an upper limit d, a lower support limit b, and an upper support limit c, of which a < b < c < d, the top flat d and c have a full membership degree of 1.0. For instance, in the case of window size, as supported by Central Public Works Department (2006), window size from

1800mm x 1200mm (2.16 m^2) and above is considered large hence the two values at the flat top (d and c) for "Large Window" MF had a minimum value of 2.16m. Window size from 1200 mm x 1350 mm (1.62m^2) to 1500 mm x 1200 mm (1.8m^2) is next to large window size, this was referred to as Medium size window in this study, hence the minimum and maximum flat top values for this MF were 1.62m and 1.8 m respectively."Small size window" is between 900 mm x 1350 mm (1.22m) and 1200 mm x 1200 mm (1.44m), hence the two values were used for d and c respectively. Table 1 to Table 4 showed the detailed input interval while Table 5 displayed the output variable intervals.

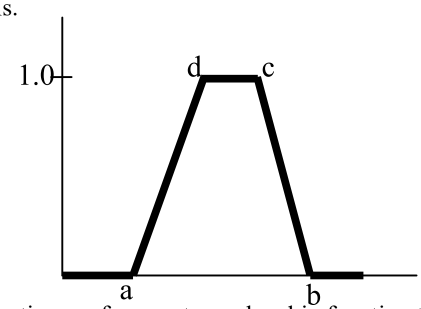

Figure 1: Typical continuous fuzzy set membership function trapezoidal shape

Table 1: Fuzzy set of input variable 'Window Size'

Linguistic Terms	Interval
Small Window (SW)	1.08, 1.2, 1.44, 1.6
Medium Window (MW)	1.44, 1.6, 1.80, 2.1
Large Window (LW)	1.90, 2.1, 4.50, 4.5

Table 2: Fuzzy set of input variable 'Roof Size'

Linguistic Terms	Interval
Small Roof (SR)	03, 06, 08, 10
Medium Roof (MR)	08, 10, 14, 15
Large Roof (LR)	13, 16, 20, 29

Table 3: Fuzzy set of input variable 'Internal Capacity'

Linguistic Terms	Interval
Small Capacity (SC)	000, 000, 200, 210
Medium Capacity (MC)	200, 210, 250, 300
Large Capacity (LC)	250, 300, 470, 470

Table 4: Fuzzy set of input variable 'Exposed Wall Size'

Linguistic Terms	Interval
Small Size (SS)	04, 06, 08, 09
Medium Size (MS)	08, 09, 13, 17
Large Size (LS)	13, 17, 24, 24

Table 5: Intervals of output variable 'Cooling Capacity'

Values	Interval
1	2600, 2800, 3000, 3200
2	3000, 3200, 3400, 3600
3	3400, 3600, 3800, 4000
4	3800, 4000, 4200, 4400
5	4200, 4400, 4600, 4800
6	4600, 4800, 5000, 5200
7	5000, 5200, 5400, 5600
8	5400, 5600, 5800, 6000
9	5800, 6000, 6200, 6400
10	6200, 6400, 6600, 6800
11	6600, 6800, 7000, 7000

2.7 Rules and Inference Generation

Eighty-one (81) fuzzy linguistic rules in the form of "IF-THEN" were generated and 'fired' by Mamdani's fuzzy inference method and centroid defuzzification of the fuzzy output. The "IF ... AND..." parts are generated from the input data, and the "THEN" part is generated from the output data. The choice of adopting fuzzy "IF-THEN" rules was because it allows available experts' knowledge to be included and allow to evaluate good approximations of desired attribute values in a very efficient way (Yager *et al.,* 1989). Of all inference systems, Mamdani is one of the most common types. Mamdani method is intuitive and has widespread acceptance. It can be well suited to human input (Ross *et al*., 2010).

To formulate the initial rule base, the input space was divided into partitions (variables) and then actions are assigned to each and combination of them. The partitioning was achieved using one dimensional MF. The consequent parts of the rule represent the actions associated with each partition (Table 5). It is evident that the MF and the number of rules are related to the partitioning. Hence the four inputs andthree linguistic values for each, there are at most $3^4 = 81$ possible linguistic rules. Few of these possible rules are stated below:
Some of the base rules are as stated:

Rule 1: If (Window Size is SW) and (Roof Size is SR) and (Exposed Wall Size is SS) and (Internal Capacity is SC) then (BTUs Rating is 1)
Rule 5: If (Window Size is SW) and (Roof Size is MR) and (Exposed Wall Size is MS) and (Internal Capacity is SC) then (BTUs Rating is 2)
Rule 7: If (Window Size is SW) and (Roof Size is SR) and (Exposed Wall Size is LS) and (Internal Capacity is SC) then (BTUs Rating is 3)
Rule 12: If (Window Size is SW) and (Roof Size is LR) and (Exposed Wall Size is SS) and (Internal Capacity is ML) then (BTUs Rating is 4)
Rule 16: If (Window Size is SW) and (Roof Size is SR) and (Exposed Wall Size is LS) and (Internal Capacity is ML) then (BTUs Rating is 5)
Rule 26: If (Window Size is SW) and (Roof Size is MR) and (Exposed Wall Size is LS) and (Internal Capacity is LC) then (BTUs Rating is 7)
Rule 53: If (Window Size is MW) and (Roof Size is MR) and (Exposed Wall Size is LS) and (Internal Capacity is LC) then (BTUs Rating is 9)
Rule 81: If (Window Size is LW) and (Roof Size is LR) and (Exposed Wall Size is LS) and (Internal Capacity is ML) then (BTUs Rating is 10)

2.8 Implementation of RACRES

RACRES was implemented in MATLAB software. MATLAB stands for MATrix LABoratory and the software is built up around vectors and matrices. It is a programming language (similar to C) which allows matrix manipulation, plotting of functions and data, implementation of algorithms and creation of user interfaces (Kristian, 2009). It provides symbolic solution and a visual plot of the result (Waleed, 2013).

3 RESULTS AND DISCUSSION

The fuzzy inference systems editor defines the fuzzy base class, as shown in Figure 2. Figures4 to 7however, show the MF graphs of all the MFs associated with all of the input and output variables for the entire fuzzy model inference system. With 95% confidence interval for the difference, -627.8 and 425.6 were recorded for upper and lower boundary respectively with standard error difference of 260.2.

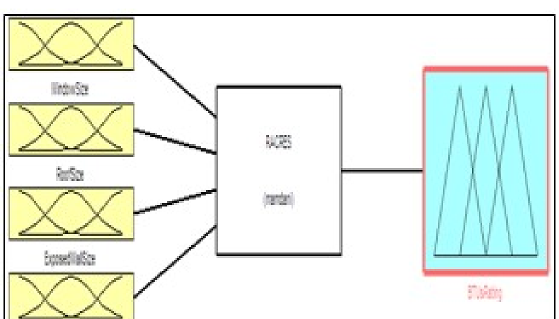

Figure 2: The fuzzy inference systems editor showing all input variables of RACRES

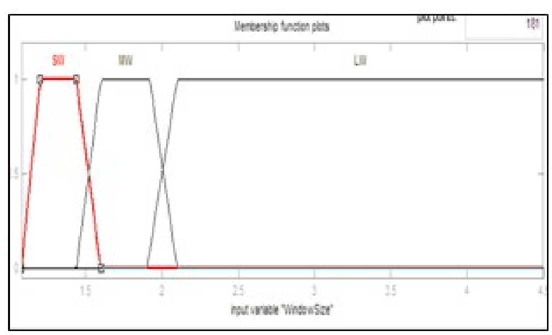

Figure 3: All membership functions for the input variable 'Window Size (sqm)'

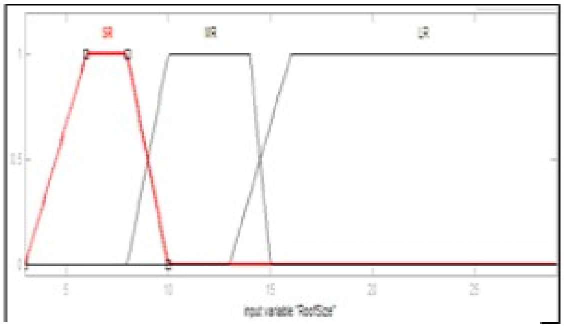

Figure 4: All membership functions for the input variable 'Roof Size (m^2)'

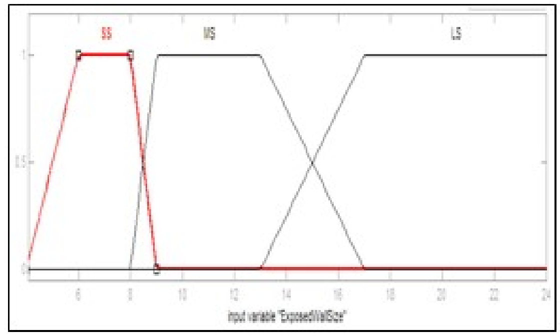

Figure 5: All membership functions for the input variable 'Exposed Wall Size (m^2)'

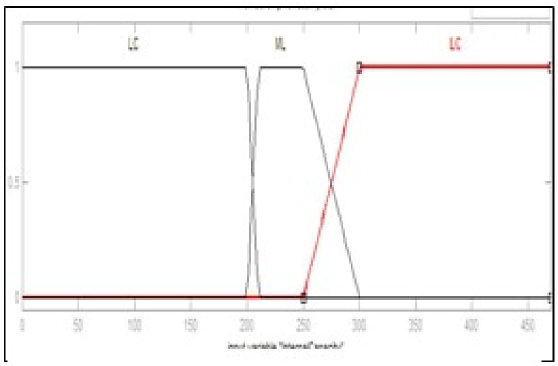

Figure 6: All membership functions for the input variable 'Internal Capacity (Watt) '

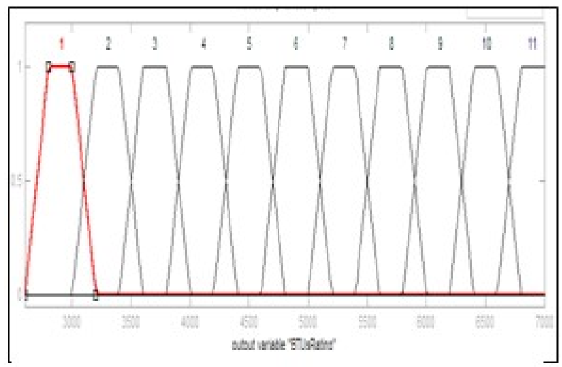

Figure 7: All membership functions for the output variable 'Cooling Rating (BTUs)'

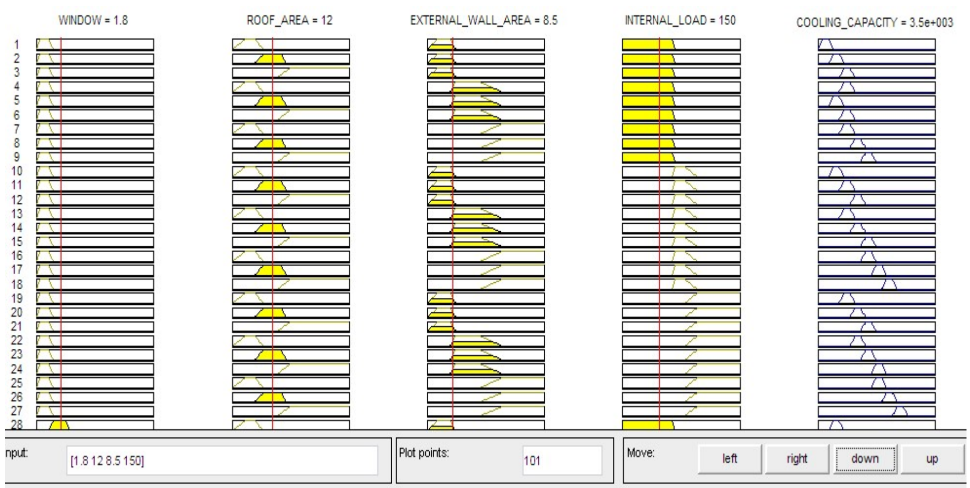

Figure 8: An interface of the RACRES

Considering the scenario of a subject with the following measured task variables; Window size = 1.8m^2, Roof size =12m^2, Exposed wall size = 8.5m^2 and internal capacity load = 150 watt, the input membership function (IMF) for variable "Window size" from Figure 4, is 1.0 (MW) (μMW (Window size) =1.0). The IMF for variable "Roof size" from Figure 5, is 1.0 MR (μMR (Roof size) =1.0). The IMF for variable "Exposed wall size" from Figure 6 is 0.5 (SS) (μSS (Exposed wall size) = 0.5) and 0.5 (MS) (μMS (Exposed wall size) = 0.5). The IMF for variable "internal capacity" from Figure 7 is 1.0 (LC) (μLC (internal capacity load) = 1.0). Combining the rules, the following logical implication statements are applicable:

Rule 29: If (Window size is MW) and (Roof size is MR) and (Exposed wall size is SS) and (internal capacity is LC) then (SRP-Risk is 2)

Rule 32: If (Window size is MW) and (Roof size is MR) and (Exposed wall size is MS) and (internal capacity is LC) then (SRP-Risk is 3)

Each of the rules was first quantified with fuzzy logic to perform inference, by quantifying the meaning of the premises of the rules. To decide the applicability of each rule (matching) the inference mechanism determined which of the rules is or are ON (i.e., if its premises MF) $\mu_{premise}$ [Window size, Roof size, Exposed wall size, internal capacity] >AA 0. The inference engine combined the recommendation of all the rules that are on, to come up with a single conclusion. The final stage was the defuzzification which operated on the implied fuzzy set (output fuzzy set) produced by the inference mechanism and combined their effects to provide the 'most certain' risk output of 3500 BTUs rating as displayed through the expert system interface shown in Figure 8.

Figure 9and 10 are contributions of two inputs ("internal capacity" and "window size") contributed to changes in the output value (BTUs rating). As the variable "internal load" increased to a value of 200 Watts and above, the BTUs required increased. The size of the window equally influenced the amount of BTUs required to cool the room. Figure 11therefore, show the presentation of the surface viewers describing the model as it varies over the ranges of its variables. It examined the output surface of the fuzzy inference system for the two inputs (internal capacity and window size) at a time.

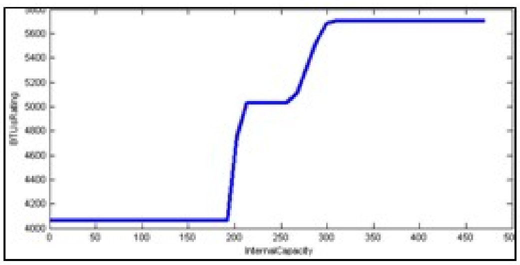

Figure 9: Relationship between "internal capacity" variable and BTUs rating

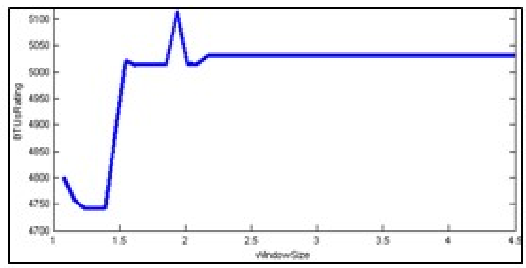

Figure 10: Relationship between "window size" variable and BTUs rating

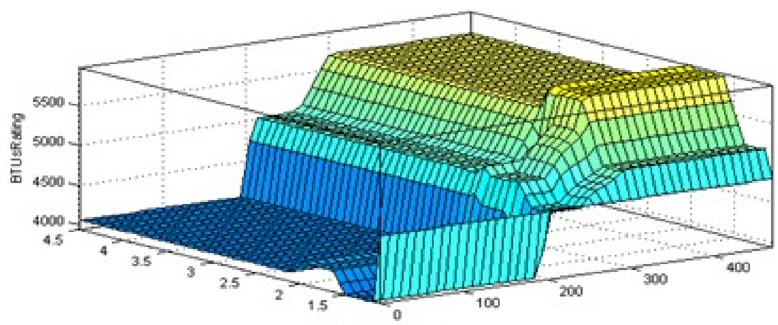

Figure 11: Surface found by mapping of the RACRES (with variables; "window size" and "internal capacity").

Table 6 is a list of randomly selected twenty samples among the several variables data recorded for the development of the expert system. The results of the HEC are displayed. The same sets of data were run with the developed RACRES and the prediction values are outlined. Unlike RACRES result presentation, HEC values were presented in decimals which required further mathematical operations to round it up.

3.1 RACRES Performance Test

3.1.1 Correlation test

The Spearman's rho correlation coefficient of the two sets of variables (HEC and RACRES values) was found to be 0.838 while that of Pearson was 0.904. The p-value obtained (0.000 and 0.000 respectively) were below 0.01 hence, so there is confident that there is a strong correlation between the two sets of values generated by HEC and RACRES.

3.1.2 Independent-samples t-test

The result of independent-samples t-test which appraised whether means for the two independent groups (HEC and RACRES)are significantly different from each other, found that RACRES had a statistically significantly higher level of predicted risk values (mean=4390, SEM=194.4) compared to HEC (mean= 4289, SEM = 173.01), with $t(38) = -0.389$, $p = 0.462$. However, with "Sig. (2-tailed)" value greater than 0.05, the groups' means are significantly not different.

Table 6: Variables recorded from 20 randomly selected cases, HEC BTUs ratings and RACRES BTUs predictions for the residential room areas.

S/N	Window Area (m^2)	Roof Area (m^2)	Exterior Wall Area (m^2)	Internal Load				HEC BTUs	RACRES Predicted BTUs
				People (No.)	Appl. (Watt)	Light (Watt)	Total (Watt)		
1.	2.16	8.1	7.56	2	80	36	116	3110.58	3700.0
2.	3.84	17.28	9.99	3	180	90	270	4538.40	4770.0
3.	1.44	9.6	8.16	2	60	72	132	3032.50	3290.0
4.	1.64	9.6	8.64	3	180	90	270	3793.84	4100.0
5.	3.84	8.64	6.46	1	140	90	230	3499.65	3700.0
6.	1.64	9.72	11.34	3	240	72	312	4191.10	4430.0
7.	2.88	11.52	12.2	2	180	90	270	3639.10	4200.0
8.	3.36	12.96	9.99	4	70	36	106	3925.10	3700.0
9.	2.16	11.52	11.34	2	180	72	252	3853.31	4400.0
10.	4.36	28.8	9.68	3	250	72	322	5165.94	5700.0
11.	4.36	9.72	23.34	3	250	108	358	5819.03	5400.0
12.	2.88	18.6	10.92	4	250	126	376	5979.53	5700.0
13.	1.44	6.5	4.16	2	170	54	224	4125.21	3600.0
14.	3.36	27.9	10.56	2	100	90	190	4719.24	4200.0
15.	3.36	18.8	9.24	2	170	72	242	4781.61	4400.0
16.	3.84	27.9	4.16	5	370	72	442	5614.55	5700.0
17.	2.88	23.0	10.56	3	70	90	160	3609.21	3700.0
18.	1.44	9.6	10.56	3	170	54	224	3782.13	4210.0
19.	2.88	23.04	10.56	4	250	108	358	4931.57	5200.0
20	3.40	12.8	10.46	2	70	108	178	3666.09	3700.0

With 95% confidence interval for the difference, -627.8 and 425.6 were recorded for upper and lower boundary respectively with standard error difference of 260.2.

3.1.3 Root Means Square Error (RMSE)

The result of this test provided a complete picture of the error distribution of the two sets of variables. Fourteen (14), representing 70% of the tested total, had values of RACRES higher than that of the HEC. In this case, the mean of the RACRES values was 4390, which were 101.1 higher than the mean of the HEC (4289). Hence the RACRES are biased 101.1 /20 = 5.01 degrees too high than HEC BTUs ratings, indicating some degree of overprediction by RACRES. The RMSE was 375.8 with the highest error noted being 589.4 in case 1.

3.2 Discussion

According to ASHRAE, (2001), a cooling load calculation determines total sensible cooling load due to heat gain through structural components (walls, floors, and ceilings); through windows; caused by infiltration and ventilation; and due to occupancy. The expert system proposed by this study, Room Air Conditioner Rating Expert System (RACRES), was developed using heat gain through exposed walls, roof, windows and internal capacity load (occupancy) as its input variables.

The expert system was tested with sets of variables and was found capable of predicting cooling load requirement for specific room variables in BTUs rating. Comparisons between RACRESand human expert calculations (HEC) were carried out in order to evaluate the performance of the system. 70% of all total prediction by RACRES was higher than that of the human calculation. This may be necessary because, according to ASHRAE (2001) residential loads are largely affected by outside conditions, thus, an oversized unit may be required especially for cooling in areas of high dry-bulb temperature.

RACRESpredictions were statistically compared to that of HEC results for the same set of input values. The results obtained were satisfactory as correlation strength was strong and t-test for means was significantly not different. The few errors recorded for RACRES' as compared to HEC may be due to the weakness of the used dataset, which tends to reduce the accuracy of the predictions, especially in case 1 where the highest error of 589.42 BTUs was recorded. In other words, according to ASHRAE (2001), even though occupant density is low, occupancy loads should be estimated. In the process of following this guideline, it may be possible that human expert overestimated the number of occupants during manual calculation which may have lead to some level of error.According to Ken and Keke (2011), accuracy in modelling is a function of bias such that obtaining a more precise estimate without increasing bias implies that the model prediction is more accurate. The degree of bias (5.01) and low level of RMSE of 375.8 results obtained provideda very respectable result for the model performance.

There are uncertainties connected to right-sizing of the air conditioning system. According to Bhatia (2012), thermal comfort requirement of an individual varies. Though related parameter combinations cannot be changed, and/or make wider for each user separately, the fuzzy logic approach can handle uncertainty, imprecision, and subjectivity in the evaluation process (Zadeh, 2006). Considering the classification of "internal capacity" of 204 Wattand another with load increments of 2 Watts (206 Watts) for instance, the value of the former fits into "large capacity" (LC) with membership degree of 0.75 and the later fits into "Medium load" (ML) with membership degree of 0.7. Hence the expert system was sensitive to such minimal changes. RACRES used a fuzzy logic technique which clearly mapped out some advantages over using manual methods of calculation in dealing with such problems as sizing air conditioning loading capacity because RACRES can be used as a computerized representation of human experts in the application area. It provides a model structure that requires intending air conditioner users to make explicit purchase decisions on the capacity of BTUs needed to cool an occupied room. If the exact predicted rating is not available in Market, the nearest in capacity to it can be selected. RACRES is simple to use and a cheap device for home builders. It is hoped that this development will minimize major involvement of human experts in this application area especially for residential houses under the climate region of the studied area and where relevant human experts are too expensive to hire.

However for further efforts, the inclusion of more variables which may increase the performance of the system like sensible cooling load due to heat gain through, floors, ceilings, infiltration, and ventilation can be considered. Additionally, 'window size', window glazing and orientations, the roof of top floor room all have a significant effect on cooling load but were lightly considered in this study.

4. CONCLUSION

This study developed a fuzzy expert system called Room Air Conditioner Rating Expert System (RACRES) with four input variables; window size (m^2), roof size (m^2), exposed wall size (m^2), and internal capacity (Watt). The amount of cooling required is the output. Arising from the findings, 70% of the total tested cases had values of RACRES higher than that of the human calculated values. However, Spearman's rho correlation coefficient of the results of human calculated values and that of the RACRESwas found to be 0.838. The result of independent-samples t-test also found that RACRES had statistically significantly higher level of predicted risk values compared to human calculated. However, the groups' means are significantly not different. The highest error noted being 589.4 degree errors with the root mean square error of 375.8. Hence, RACRES' performance satisfied the objectives of this study. It can mimic results from human expert manual calculations for residential building air conditioning rating capacity. It is simple to use and a cheap device for home builders most especially where services of relevant human experts are too expensive to hire.

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Nomenclature List for the Parameters Used

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTUs	British Thermal Units
CLTD	Cooling Load Temperature Difference
HEC	The Human Expert Calculations
HVAC	Heating, ventilation, and *air conditioning*
MF	membership function
qrm	Room sensible cooling load (W)
Qwt	Total airflow (L/s)
RACRES	Room Air Conditioner Rating Expert System
RMSE	Root mean square error
SEM	Standard error of mean
Ud	Heat Transfer Coefficient (for door)
Ur	Heat Transfer Coefficient (for room
Uw	Heat Transfer Coefficient (for external wall)