International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 3, March, 2012

Design and Development of Calculator Software for Residential Electrical Services Design

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ABSTRACT

This paper presents the design and development of Calculator software for residential electrical services design. The software was developed using Java programming language and it serves as a valuable design tool for electrical engineers, students and technicians by providing a faster, easier and more accurate means of carrying out some basic calculations such as; determination of number of lighting fixtures required in a room, the design current and power required per final sub-circuit, the total connected load, voltage drop across chosen cables and load balancing across the three phases of a three-phase supplied building. The results of these calculations help the designer to make vital decisions such as types of luminaries, sizes of cables and nominal ratings of protective devices required by each circuit and by the entire installation in line with appropriate standards and regulations.

Keywords: *Calculator, electrical, lighting, sub-circuit, voltage-drop, conductor, protective device, power, load-balancing.*

1. INTRODUCTION

Every electrical installation in residential or industrial buildings is preceded by a careful plan or design. Designs for building installations involves various calculations based on several factors which includes; type of building, purpose of building and of the installation, physical building parameters, standards and regulatory bodies such as the IEE (Institute of Electrical Engineers) and NEC (National Electrical Code) [1].

In order to avoid the fatal consequences of poor or sub-standard electrical designs, which include, fire outbreaks leading to loss of lives and properties, damages to electrical equipments and to their users, use of wrong ratings of conductors and insulators etc. It is important that designs be handled by professionals i.e qualified Electrical Engineers. Calculation is a basic tool used by Electrical Service designers to achieve the desired result.

These calculations include:

- Load calculation based on the number and type of electrical load to be used in the building.
- Lighting fixture calculations
- Switchgear ratings calculations
- Conductor size calculation. Etc.

In view of the importance of electrical service design calculations, it is expedient that measures to ease professional designers of manual calculation stress and eliminate the tendencies of mistakes during calculations be developed, hence the need for software such as the one under review.

1.1 Review of Existing Electrical Design Calculator Software

Residential Electrical design requirements, methods and standards have developed over the years in line with the growth and level of sophistication of the society. Software packages have therefore also been created to meet specific electrical design needs.

Although some of these calculator softwares are quite robust with wide area of application, most of them do not make specific provision for residential electrical design.

The NEC calculator is a suite of tools that performs electrical design calculations for conduit fill, conductor sizing, motors, transformers, power factor, fault current, voltage drop, box fill and sizing, lighting design, panel directories, custom conductors [1]. The calculation is fully compliant to NEC (National Electrical Code) specifications. Although NEC is an American standard organization, its specifications are being used in other parts of the world. Some other countries such as Nigeria, however, use the British standards; hence, the IEE (Institute of Electrical Engineers) regulation is the ideal for wiring services in the country.

Ecodial is software by Merlin Gerin – Schneider Electrical. Its purpose is to perform calculations for low voltage distribution network. With Ecodial, the panel board and breakers to loads can be inserted with the aid of the computer and the size of the breaker, cable and short

circuit current are calculated. It also helps to verify the discrimination between the breakers with various trip units, types, and settings [2].

The few calculator softwares that accommodate residential design calculations make use of a method that assumes the load requirement of the home on the basis of its area. In contrast, this work presents a model which gives room for the designer to work with specific loads anticipated or required by client with consideration to the peculiar load characteristics such as power factor. This software calculates the apparent power, which is the amount of power required from the supply to end user, it also makes provision for diversity in the actual usage of these load. All quantitative design factors used in the calculations (diversity factor, utility factor, maintenance factor, power factor) are open for the designer to input, thereby increasing design flexibility.

A major advance of this work is the inclusion of a load balancing module. The interface was created in tabular form to accept the inputted loads descriptions and corresponding values. It then logically distributes the loads into the three phases; Red, Yellow and Blue phase. This feature of the software was found to be very efficient and its use is not limited to residential loads as the algorithm for the load balancing depends essentially on the relative magnitude of the inputted loads.

2. DESIGN METHODOLOGY

This software was developed using Java 2 Standard Edition and meant to run on a stand-alone Personal Computer. Programming with Java was preferred due to its relative ease of use, portability and compatibility with several platforms and operating systems [2]. The user interface was designed using Netbeans 6.8 development environment due to the availability of several design options and capabilities. The work consists of four major modules controlled by the main interface, namely; lighting, final sub-circuit, voltage drop/cable sizing and load balancing module. These modules can function independently to give the required results. The software was designed to be interactive and user friendly, accepting inputs from users to carry out specified calculation at the click of a button. The results of these calculations are displayed either in a table in separate window or in a text field within the window where the data were entered. The welcome page and the calculation option pages are shown in figures 2.0 and 3.0.

The software design was made following the pattern described in the block diagram in figure 1.0; the user interacts with the various calculation interfaces through the main interface. He enters the appropriate inputs into any interface of choice, e.g; lighting, final circuit, voltage drop or load balancing. The inputs are processed by the *main interface* as programmed, and the result is presented as output to the user. Where applicable, an interface sends a request to print a result table, to the main interface through the *print spooling*.

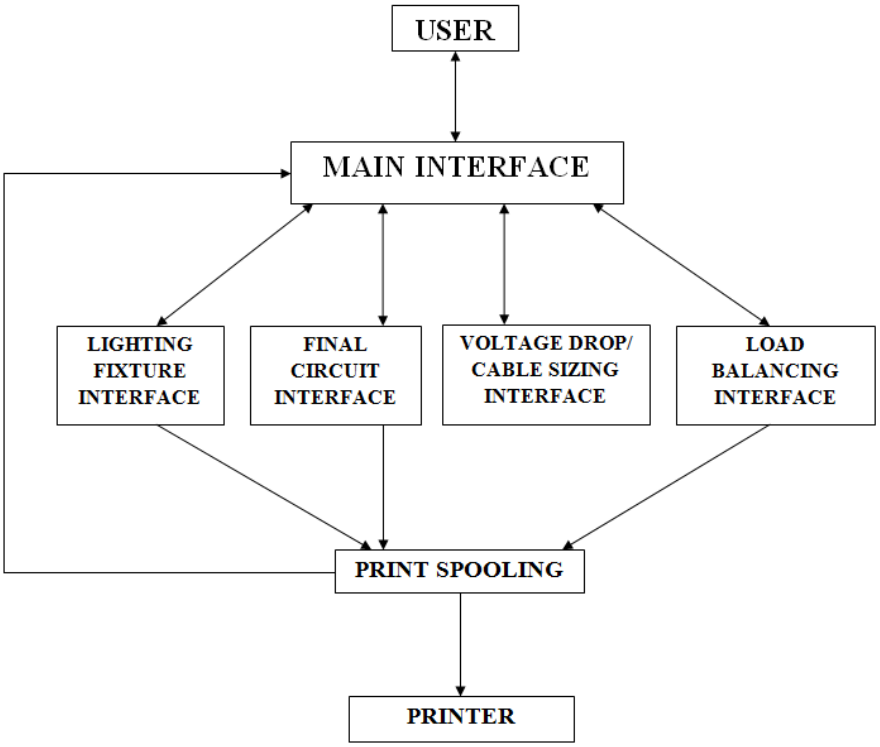


Figure 1. Software Design Methodology Block Diagram

Figure 2. Software Welcome Page

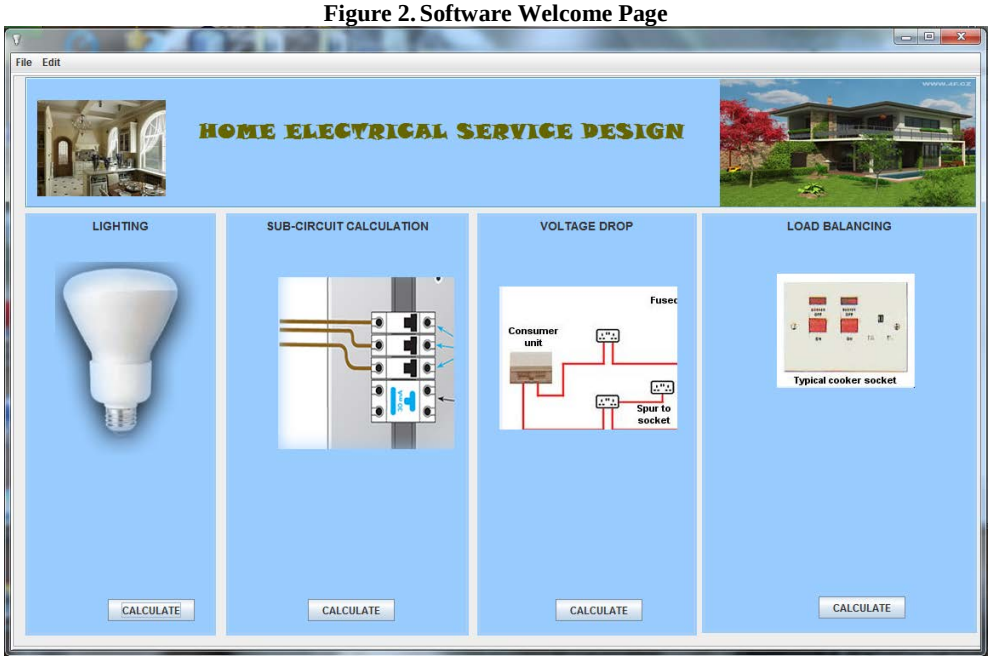


Figure 3. Calculation Option Page

2.1 Lighting Fixtures Calculation Interface

The lighting calculation interface displayed in figure 3.0 accepts the following inputs; *room description, area in square meter, required luminous intensity, bulb description and luminous intensity,* to calculate the required number of bulbs for area entered.

The following formulas were used in accordance with the lumen method of lighting calculation [3]

Total luminous flux,

$$\varphi_{tot} = \frac{E \times A}{UF \times MF} \quad (1)$$

No of lamp,

$$N = \frac{\varphi_{tot}}{\varphi_L} \quad (2)$$

Where

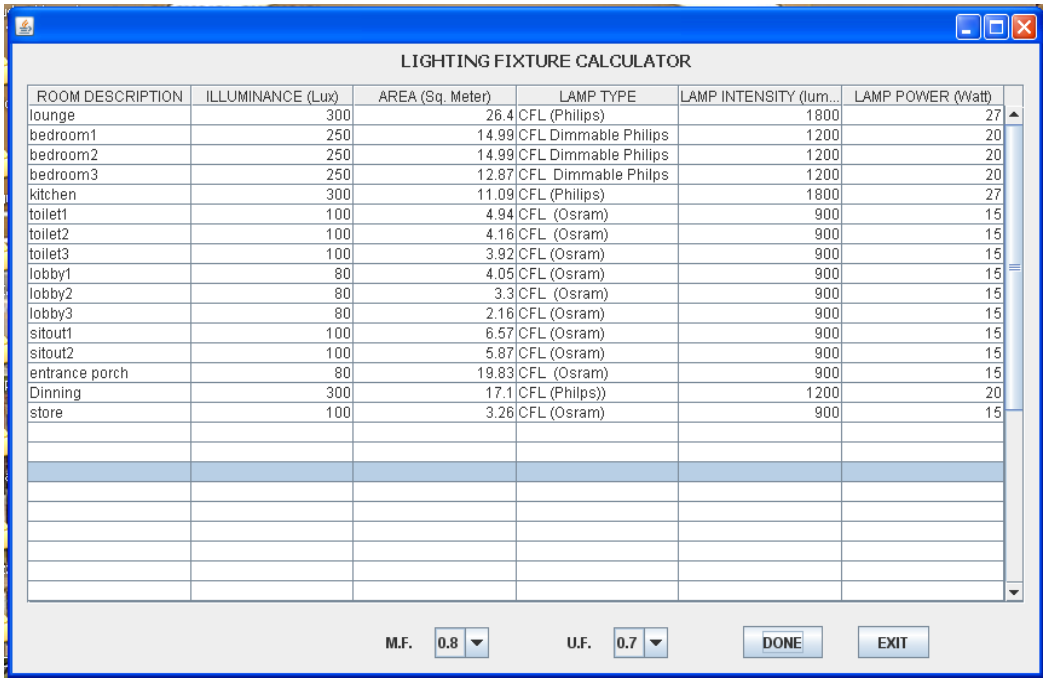
E = illuminance in lux,

A = Area of room in metre square

φ_L = the luminous flux of one lamp in lumen

UF = utility factor

MF = Maintenance factor



ROOM DESCRIPTION	ILLUMINANCE (Lux)	AREA (Sq. Meter)	LAMP TYPE	LAMP INTENSITY (lum...	LAMP POWER (Watt)
lounge	300	26.4	CFL (Philips)	1800	27
bedroom1	250	14.99	CFL Dimmable Philips	1200	20
bedroom2	250	14.99	CFL Dimmable Philips	1200	20
bedroom3	250	12.87	CFL Dimmable Philps	1200	20
kitchen	300	11.09	CFL (Philips)	1800	27
toilet1	100	4.94	CFL (Osram)	900	15
toilet2	100	4.16	CFL (Osram)	900	15
toilet3	100	3.92	CFL (Osram)	900	15
lobby1	80	4.05	CFL (Osram)	900	15
lobby2	80	3.3	CFL (Osram)	900	15
lobby3	80	2.16	CFL (Osram)	900	15
sitout1	100	6.57	CFL (Osram)	900	15
sitout2	100	5.87	CFL (Osram)	900	15
entrance porch	80	19.83	CFL (Osram)	900	15
Dinning	300	17.1	CFL (Philps))	1200	20
store	100	3.26	CFL (Osram)	900	15

Figure 3. Lighting Calculation Interface

Provision was made for selection of maintenance factor and utility factor from a drop down list.

2.2 Final Sub-Circuit Calculation

This is aimed at calculating the total load per final sub-circuit with the corresponding current demands in order to aid the choice and rating of protective device to be used. The calculation formula and method used depends on the type of final sub-circuit being considered. Generally, the design current of a given circuit is calculated thus [3]:

$$I = \frac{circuit\ load\ in\ watt}{nominal\ voltage\ \times efficiency\ \times power\ factor} \qquad (3)$$

Note that, the nominal supply voltage in the country (Nigeria) is 230V single phase and 400V three phase.

2.2.1 Lighting Sub-Circuit

The type of lamp used in the installation is taken into account as shown in the lighting sub-circuit section of figure 3.0. The fluorescent lamp, incandescent lamp and compact fluorescent lamp types are considered separately for calculation to accommodate their differences in electrical characteristics.

Fluorescent lamp: The multiplication of power by 1.8 is to take power factor into account in accordance with IEE regulation for discharge lighting circuit calculation [4].

Apparent power (VA) = rated power (Watt) × 1.8 (4)

Incandescent Lamp: incandescent lamps are purely resistive; hence the power factor is 1.

Power (VA) = rated power (Watt) (5)

Compact Fluorescent Lamp:

Power (VA) = rated power (Watt)/power factor (6)

In calculating the demand current, a diversity of 66% is allowed as recommended for household lighting installation (IEE Regulation Appendix 4, Table 4B) [4].

Ceiling Fan: Ceiling fans are usually connected in the same circuit, and protected by a single protective device as lighting loads. The rated power of a ceiling fan is about 200 watt. A separate circuit can however be dedicated to ceiling fans especially when they are significantly much in number.

2.2.2 Single Circuit Appliances

This sub-section (figure 3.0), refers to appliances that occupy a separate way with a fuse or protective device on the distribution board. This is either due to their high power demand or other primary characteristics such as high starting current requirement and frequency of use.

Cooker Unit: Electric cooker, like other electrical heating loads, is purely resistive. Hence power factor is 1 and the rated power in watt equals apparent power (VA). Diversity

factor is applied to the rated current to obtain the current demand of the unit as shown below (IEE Regulation Appendix 4, Table 4B) [4].

Current demand = first 10A of the rated current + 30% of the remainder of the rated curren +5A (7)

Air Conditioner:

$$\text{power (VA)} = \frac{\text{Rated power (watt)}}{\text{Efficiency} \times \text{p.f}} \quad (8)$$

Current demand = power (VA) / 230V. (9)

These general formulas are also used for evaluating the power and demand current of single phase motors and electric pumps.

Water Heater: The power in VA equals the rated power in watt being a purely resistive load.

Three phase Equipment: For a 3-phase load, the power (VA) is evaluated using equation (8). Demand current evaluation however differs only in the use of nominal line voltage.

Current demand = power (VA) / 1.73× 400V (10)

2.2.3 Socket Outlet Final Circuit Calculation

13A socket outlets used for domestic home appliances such as television, CD and video players, refrigerators, pressing iron and other common low power-consuming appliances may be supplied through a ring final circuit protected by a 30 or 32A protective device and wired with copper conductor having line and neutral conductors with minimum cross-sectional area of 2.5mm^2[5]. A single 30A ring circuit may serve a floor area of up to 100m^2 [5]. For design purpose, a value of 300W per point was assumed in this design.

2.2.4 Total Demand Calculation

This section calculates the total demand for a single dwelling or building.

Total flat or building load demand in VA = sum of final sub-circuit loads in VA (11)

$$\text{Maximum Demand current} = \frac{\text{load demand (VA)} \times \text{diversity factor}}{1.73 \times 400\text{V}} \quad (12)$$

Figure 4.0 shows the final circuit calculation module.

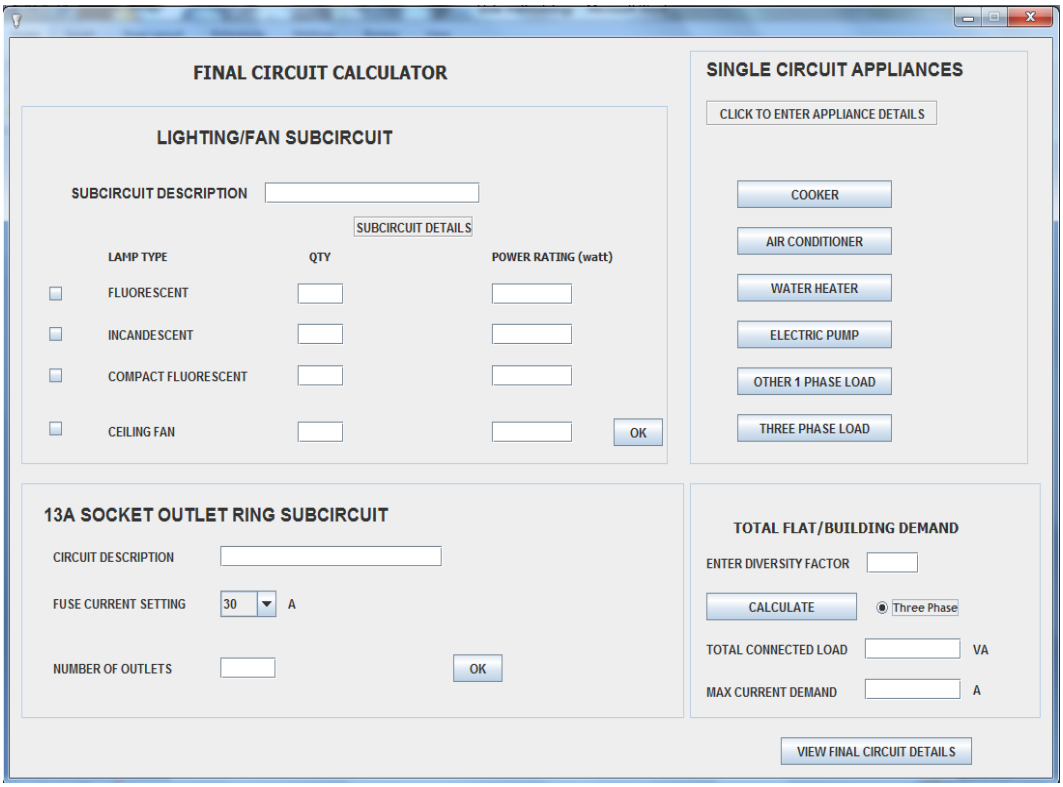


Figure 4. Final Circuit Calculation Module

2.3 Cable Size Calculation Module

The appropriate cable size to be used for connecting a circuit load and the power supply source is estimated using the design current I_b of the circuit and the current setting I_n of the circuit protective device as follows [6]:

Step 1: I_n is first chosen to be ≥ design current I_b

Step 2: The chosen value of I_n is divided by the appropriate correction factor where applicable to obtain the effective current-carrying capacity of the conductor. For domestic installations, correction factor may not be considered since the conditions are not usually applicable and the ambient temperature is taken as 30°C.

Step 3: The cable size corresponding to the tabulated current-carrying capacity is chosen from the IEE regulations Table for cable size and voltage drop specifications, based on the installation method and the type of cable.

Step 4: The voltage drop along the cable is calculated using the formula:

$$Voltate\ drop = \frac{tabulated\ voltage\ drop \times circuit\ design\ current(A) \times length(m)}{1000} \quad (13)$$

The result is compared with the specified maximum allowable voltage drop value which is 2.5% of the nominal supply voltage. (i.e. 2.5% of 230V = 5.75V for single phase supply and 2.5% of 400V = 10V for three phase supply).

Consideration of voltage drop is negligible for short cable runs like in domestic buildings but it was incorporated for calculating cable size for connections between similar buildings which may be some metres apart or for connections between a building and the service supply point. For cables supplying high power-rated single device sub-circuit, voltage drop may also be considered.

2.4 Load Balancing Algorithm

The balancing of loads between three phases; Red, Yellow and Blue phases, was achieved using the algorithm below.

1. Accept inputted load values with corresponding load description.
2. Distribute the loads randomly into three containers (phases); Red, Yellow and Blue
3. Sum the loads in each phase
4. Compare the load sum in the three phases. Get the smallest and the largest.
5. Get the difference between the highest and the least loaded phases
6. Halve the difference obtained in 5 above.
7. Scan through the highest loaded phase for any single load with a value less than or equal to the result in 6.
8. If such load exists, reposition it into the least loaded phase container to balance the loads else, the loads are balanced.

3. TEST AND RESULT

A 3-bedroom bungalow was considered as case study. Each module of the software was tested using this case study. Typical results obtained are shown in the snap shots figure 5.0-8.0. Based on the results obtained, the power and lighting layouts as well as the distribution board analysis for the building under study were made as shown in figures.

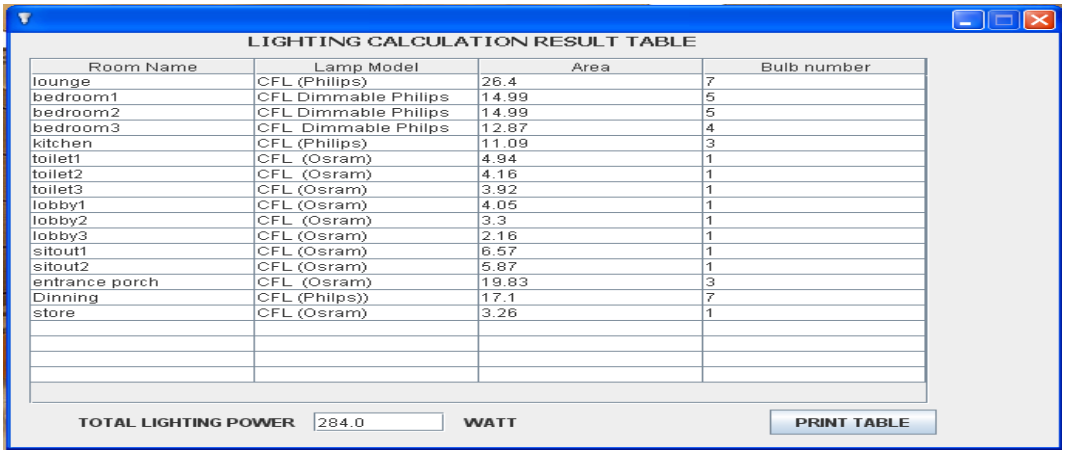


Figure 5. Lighting Calculation Result

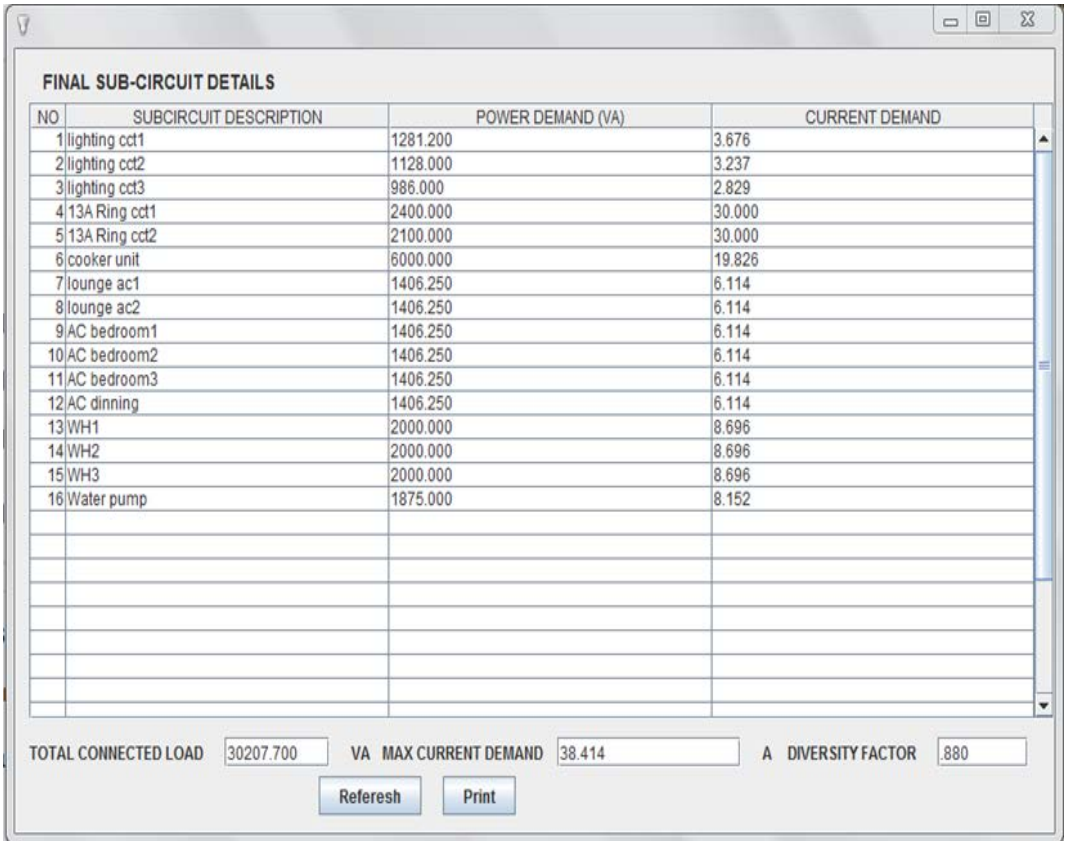


Figure 6. Final Circuit Calculation Result Showing power and current demand per circuit and total demand for entire building.

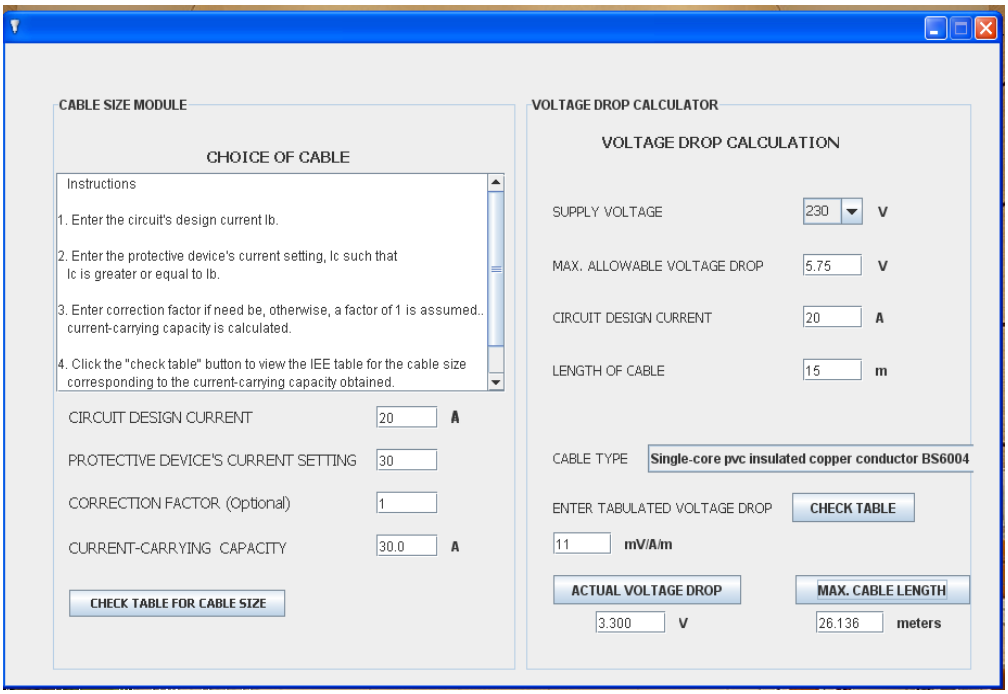


Figure 7. Voltage drop calculation for 4mm^2 single-core p.v.c. insulated cable supplying electric cooker unit.

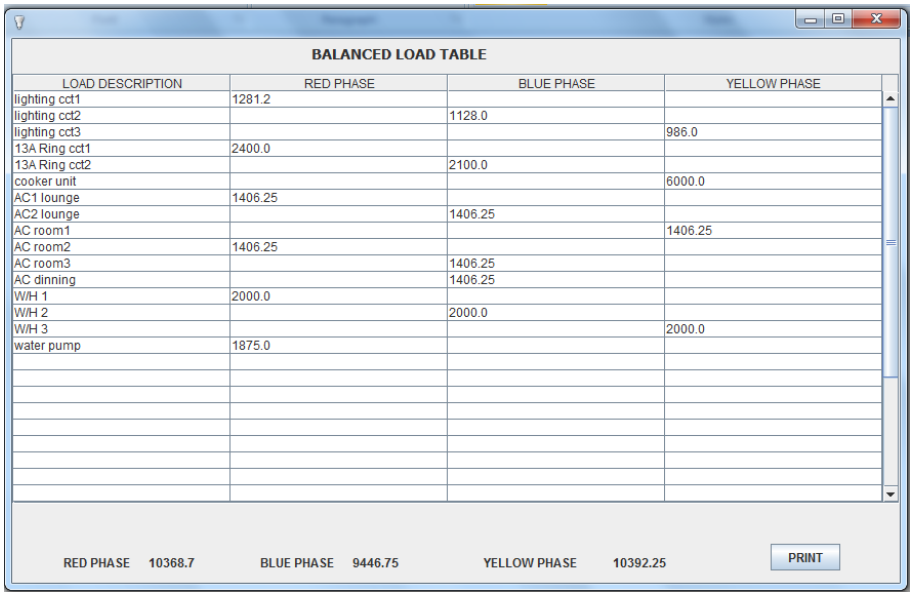


Figure 8. Balanced Load Result

4. DISCURSIONS OF RESULTS

The calculation results obtained from the use of this software was found to be very consistent with the manual calculation results, however, the time taken to complete a calculation with this software was significantly less than the time required to complete the same calculation manually. This is due to the fact that a computer system operates at a far greater speed than humans.

The software is flexible and easy to use. It minimizes tendencies of inadvertently entering wrong parameters, by prompting the user to either reject or accept the result before entering it into the appropriate result table. Result pages could also be printed, thereby providing a technical document for installation.

5. CONCLUSION

The software was found to be reasonably effective and efficient in carrying out the required electrical design calculations, at computer speed and accuracy. The software serves as a valuable design tool for the electrical engineer, student or technician by providing a faster, easier and more accurate means of carrying out some basic calculations required for residential electrical design work.

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