Journal of the Nigerian Association of Mathematical Physics
Volume **22 (November, 2012), pp 561 – 570**
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A Solar Power Design for Primary and Secondary Schools in Nigeria

[1]Ebunilo, P.O.B., [2]Izah, L. A. and [3]Sadjere, E.G.

[1]Department of Mechanical Engineering
Faculty of Engineering
University Of Benin, Benin City.
[2] Department of Mechanical Engineering
School of Engineering
Auchi Polytechnic, Auchi.
[3]Niger Delta Development Commision,
167 Aba Road, Portharcourt

Abstract

An Energy Audit survey of secondary and Primary/Nursery Schools in Auchi, a sub urban town in Edo State, Nigeria shows that though 99% of the schools are connected to the National Electricity grid,but the unreliability, inadequacy and unavailability of electricity supply has made it a necessity for the schools to have an alternative source of power supply. The survey shows that a typical secondary school requires 26.36kwh of energy while a typical primary/nursery school need 20.72kwh of energy to meet its energy requirements. This can easily by met by solar power which is renewable, environmentally friendly and sustainable instead of the conventional power from power Holding Company of Nigeria Ltd or from Petrol/Diesel generators that use fossil fuel that are non-renewable and harmful to the environment. The average cost of buying and installing a stand-alone photovoltaic system for a typical secondary school was found to be about three million, six hundred and nineteen thousand Naira (N3,619,000) while the average cost of buying and installing a stand-alone photovoltaic system in a typical primary/Nursery school was found to be about two million, two hundred and eighty eight thousand naira (N2,288,000). These costs are justifiable given the health/social benefits associated with well lit and comfortable environments that should be found in all learning institutions.

Keywords: Solar energy, Audit, Primary school, Secondary school, Electricity, Photovoltaic, cost, Design.

Abbreviations:

Ip = the primary current drawn from battery (A),
Ps = Starting power(W) ,
T=Time ,
P_{sol} = Power of one solar panel (W),
PF= Power factor,
R_p =Rated power (W),
Pin= Power rating of inverter (KVA),
Bc =Battery capacity (Ah),
Ef = Efficiency loading,
I_{charge} = Battery charge (A),
V_{charge}= Charging voltage (V)
I_s = Starting current (A) ,
IP = Primary current drawn (A) ,
I_{sol} = current of one solar panel (A),
V_{sol} = Voltage of one solar panel (V).,
L= Power losses
P= Refrigerator power (kW)
Pdv =Power delivered by one battery
Tc =Total current (A)
$I_{max,}$ = Maximum current (A)
Vsp = Voltage per solar pane (V)

1.0 Introduction

Solar energy has been harnessed by humans since ancient times using a range of ever evolving technologies [1,2]. Solar energy technologies include solar heating, solar photovoltaic, solar thermal electricity and solar architecture, which can make considerable contributions to solving some of the most urgent environmental problems facing the world today [3,4,5]. Solar

Corresponding author: ***Ebunilo, P.O.B.,*** E-mail: Ebunilo17@yahoo.co.uk, Tel. +234 8037136102

technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy while passive techniques include orienting a building to the sun, selecting materials with favourable thermal mass or light dispersing properties and designing spaces that naturally circulate air [6,7,8].

Nigeria's energy assessment indicates that she is one of the energy poor countries in the world as indicated by her electricity utilization position in the Human Development Index [9]. This report gave the 2001 Human Development Index (HDI) ranking of the united nations Development programme (UNDP) and Nigeria was ranked 151 out of 177 nations. Her electricity per caital consumption was 154kwh per annum. Nigeria dropped to 158th position in 2004 ranking with a consumption of 148kwh per capital per annum [10]. According to[11], electrical power supply in Nigeria is expensive, sporadic and is characterized by low power generation, inadequate supply and lack of access particularly by the rural populace. There are frequent power outages, load shedding and high incidence of equipment breakdown, faulty transformers and vandalization of powerlines [12]. Since Nigeria lies in the equatorial belt of the earth, it receives an average of about 3.5Kwh/m^2 per day (12.6MJ/m^2 per day) in the coastal latitudes and about 7.0 kwh/m^2 per day (25.2MJ/m^2 per day) in the far north of the country [13]. The above values are high enough for solar power plants in Nigeria and the power so harnessed can be used as alternative source of power for primary and secondary schools in Nigeria.

An Energy audit survey carried out on secondary and primary/nursery schools in Auchi shows that the schools lack electric power supply most of the time and a visit to the schools shows that they lack classroom lighting, classroom fans, boreholes which are important for hygiene and generators. The schools need between 30.34kwh to 22.54kwh of energy to power their equipment and make them more conducive for learning.

2.0 Materials and Method

Statistical survey for the collection of data on primary and secondary schools energy profile in Auchi area of Edo State was undertaken. The energy profile includes energy sources, energy consumption, utilization of electrical appliances, run time for electrical appliances etc. The parameters obtained were used to design the solar energy system that can be used as alternative energy source in primary and secondary schools in Nigeria.

Questionnaire was the major instrument used in the survey. It was designed of multiple choice formats with all the necessary information needed put in question and answer form.

The average electrical energy needs of secondary schools and the average solar power requirements was determined by the following procedure:

Table 1: Load (Power and energy for a typical secondary school)

S/N	Equipment	Qty	Rating	Power	Use time	Energy
1.	Bulbs	20	20	400	4	1.6
2.	Refrigerator	1	200	200	12	2.40
3.	Ceiling fan	24	60	1440	8	11.52
4.	Standing fan	2	60	120	8	0.96
5.	Computer	10	200	200	3	6.00
6.	Laboratory equipment	2	80	160	4	0.64
7.	Television (Plasma)	2	180	360	9	3.24
8.	Total Power/Energy			4680	48	26.36

(a) Design of the average Load (energy and Power)

Table 1 shows that the total power requirement of a typical secondary school is 4.680kw while the energy requirement is 26.36kwh. To take care of all losses in a system, a "furge factor" of 15% can be used [14].

$$L = \frac{15}{100} \times 4.680\text{kW} = 0.702\text{kW} \tag{1}$$

Total power (Load) = 4.680 + 0.702kW = 5.382kW

The above can be considered as the peak load. The base load is when most of the equipment are put off and remaining only the refrigerator, the two standing fan and five energy bulbs.

Power consumption for base load;

(i) Refrigerator rated power (P) = 200W

For inductive load starting current (on inverter) is

$$I_S = 4I_P \text{ [15]} \tag{2}$$

Where

$I_P = \frac{P}{V} = \frac{200W}{220V}$ (3)

$= 0.91A$

$I_S = 4^I{}_P = 4x0.91 = 3.6A$

Starting power

$P_s = I_S x V_S$ (4)

$= 3.64x220$

$= 801W$

(ii) For two (2) standing fan (medium),

Rated power (R_p) = 2x60W = 120W

For inductive load starting current (on inverter)

$I_P = \frac{120}{220} = 0.55A$

$I_S = 4xI_P = 4x0.55A = 2.18A$

Starting power from equation (4)

= 2.18x220 = 480w

(iii) For the five (5) energy bulbs,

Total rated power (R_p) = 5x20W

= 100W

For capacitive load, power at start up is twice the power rating

:. Start power (for the fans)

= 2x100W = 200W

Total power of the base load at start up, P_{ts} = 901+480+200

= 1481W

Losses = $\frac{15}{100}$ x 1481 = 222.15W

Total power of base load

= 1481+222.15 = 1703.15W

From Table 1, the energy consumed at this base load is

(200)x12 +(670x2) x 8 + (20x5)x4

= 3.76kWh

(b) Selection of inverter

The total power provided for as shown in Table 1 is 5.382kW. The inverter was chosen to deliver at peak efficiency -operating at 80% output load [16].

:. Total electrical power = $\frac{5.382kw}{PF}$

Where (power factor) PF = 0.8

$= \frac{5.382kw}{0.8} = 6.728kW$

7KVA inverter was chosen

(c) Selection of battery

One fully charged deep cycle battery can deliver or carry a maximum power of 1000VA.

Total number of batteries

$$Bt = \frac{Pin}{Pdv} \quad (5)$$

$= \frac{7000VA}{1000VA}$ = 7 batteries

Current through the inverter at maximum load is given by $I_S = \frac{P_S}{V_S}$ (6)

Where P_S = 7000VA

V_S = 220V

I_S = secondary current

$I_S = \frac{7000}{220} = 32A$

From bulk conversion principle

$I_P = 2I_S$ [15] (7)

From battery

:. IP = 2x32A = 64A (ideal case)

For this project 200AH/12V battery was chosen to adequately carry the current safely.

The time that the 200AH/12V battery will run is given by;

$$T = \frac{Bc}{Tc \ \ x} \tag{8}$$

$$= \frac{200AH}{64A} x0.85 = 2.7hrs \ (2hrs\ 42m)$$

For 7 batteries connected in series, total time is given by 2.7x7

= 18.9hrs (18hrs, 54 minutes)

Considering losses, the batteries can run for 16 hours with the base load connected

(d) Design of the photovoltaic array

The first centers on the power to charge the batteries only while the second centres on the power to charge the battery and supply power to run the base load.

(i) To charge the batteries

To charge a 12v battery, the recommended voltage is 15V and the charging current is 10% of the battery maximum current

$$\text{i.e } I_{charge} = 10\% \text{ of } I_{max} \tag{9}$$

where I_{max} = 200AH

$$I_{charge} = \frac{10}{100} x\ 200 = 20A$$

Since the seven (7) batteries are in series, the same charging current flows through them.

Charging voltage required (V_{charge}) = 15Vx7

= 105V

$$\text{No of Solar panels needed } N_{SP} = \frac{(V_{charge})}{Vsp} \tag{10}$$

$$= \frac{105}{24} = 4.375 \text{ panels}$$

No of Solar panels = 4panels in series (voltage charging)

Current produce by 1 solar panel,

$$I_{SOL} = \frac{P_{soL}}{V_{sol}} \tag{11}$$

$$= \frac{200}{24} = 8.3A$$

No of panels required to produce 20A current (charging current)

$$Is = \frac{20}{8.3} = 2.4 \ (3 \text{ panels in parallel})$$

For efficiency 4 panels are used to increase the current to 28.3A

(Variation in sun intensity)

Total number of panels needed to charge the batteries

= 4x4 = 16 panels (4 in series and 4 in parallel)

Fig 1 shows the connection of the solar panels

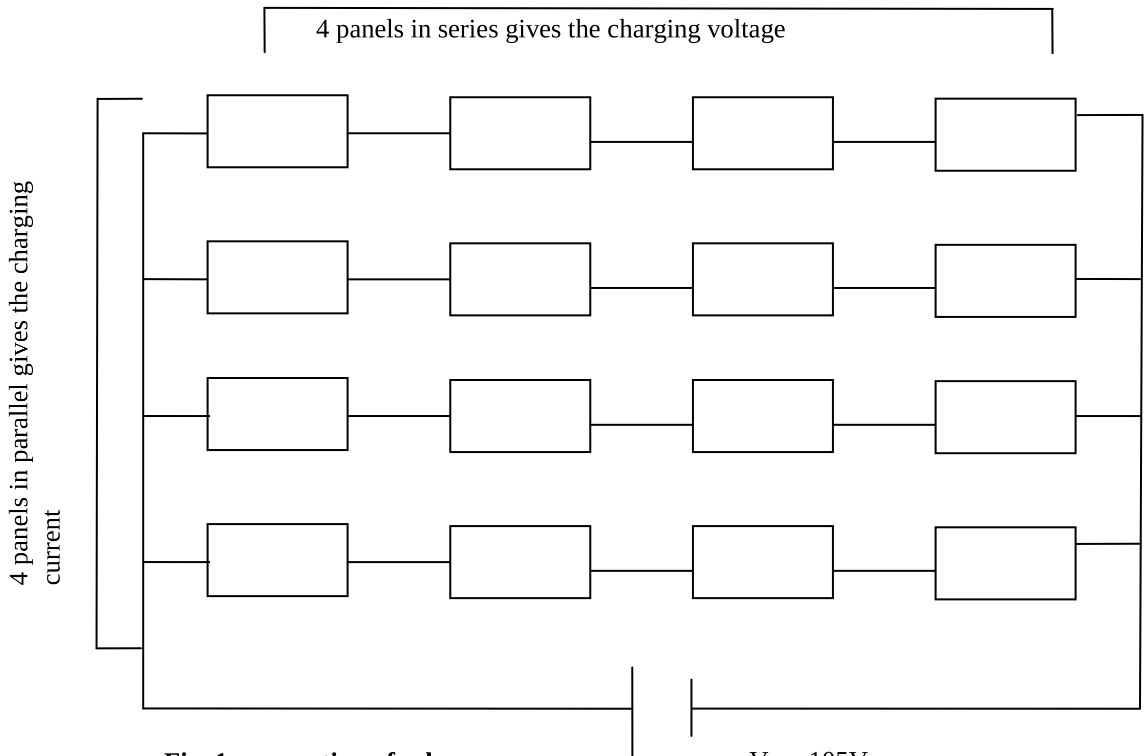

Fig. 1: connection of solar panels for charging

From computation, to carry the base load with 7KVA inverter current needed is 64A. To charge the batteries, current needed is 28.3A

Total current needed = 64+28.3

= 92.3A

No of panels require in parallel

$= \frac{92.3}{8.3}$ = 11panels in parallel

Total number of panels required

= 11x4 = 44 panels

(e) Charge controller

For maximum efficiency, the output of the solar panel must be fed into a charge controller. The charge controller (circuit) ensures that the current/voltage needed is maintained so that it does not damage the cell. For this project a charge controller of 50A-100A was chosen. See Fig.2 .

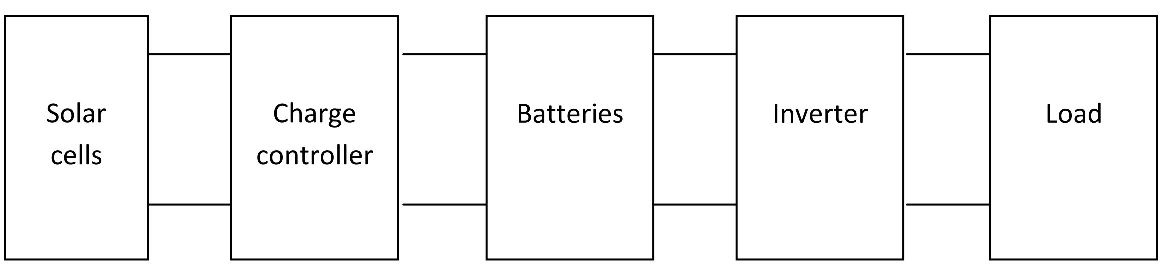

Fig 2: Block diagram showing the connection of the components

(e) Cost analysis

The cost analysis is shown in Table 2.Appendix A also shows a typical cost analysis of a nursery and primary school in Auchi area of Edo state.

Table 2: Cost analysis for a typical secondary school (Electric power)

S/N	Item	Qty	Rating	Unit cost (N)	Amount (N)
1.	Inverter	1	7KVA	120,000	120,000
2.	Battery	7	12v, 200AH	40,000	280,000
3.	Solar panel	44	200w/48v	65,000	2,860,000
4.	Charge controller	1	50A-100A	30,000	30,000
5.	Sub-total				3290,000
6.	Miscellaneous and installation (10%)				329,000
7.	Total				3,619,000

The average electrical energy needs of nursery/primary schools and the average solar power requirement was also determined by the same procedure.

(a) Design of the average Load (energy and power)

Table 3: Load (power and energy) for a typical Nursery/Primary School.

S/N	Equipment	Qty	Rating (w)	Power (w)	Usetime (h)	Energy (kwh)
1.	Point light	16	20	320	4	1.28
2.	Refrigerator	1	200	200	12	2.40
3.	Ceiling fan	18	60	1080	8	8.64
4.	Standing Fan	2	60	120	8	0.96
5.	Computer	7	200	1400	3	4.20
5.	Television plasma	2	180	360	9	3.24
6.	Total power/energy			3480	44	20.72

Table 3 shows that the total power requirement of a typical nursery/primary school is 3.480kW while the energy requirement is 20.72kWh. to take care of all losses in a system, a “furge factor” of 15% can be used [14].

Power losses (L) $= \frac{15}{100} \times 3.80 = 0.52$kW

Total power (Load) = 3.480 + 0.522 = 4.002kW

The above is the peak load. The base load is when all the equipment are put off with the exception of the refrigerator, the two standing fans and the five bulbs.

As in the first case, the total power consumed at this base load is 1703.15W while the energy consumed is 3.76kwh.

(**b) Selection of inverter**

The total power provided for as shown in appendix 3 is 4.002kW. The inverter was chosen to deliver at peak efficiency – operating at 80% output load.

Total electrical power $= \frac{4.002}{PF}$

Where (power factor), PF = 0.8

$= \frac{4.002}{0.8} = 5.003$kw

5KVA inverter was chosen

(c) Selection of battery

Total number of batteries is given by equation (5)

$$Bt = \frac{5000VA}{1000VA} = 5 \text{ batteries}$$

Current through the inverter at maximum load is given

$$I_S = \frac{5000}{220} = 22.73A = 23A$$

From bulk conversion principles

$I_P = 2I_S$

:. $I_P = 2x23A = 46A$ (Ideal case)

For this project 200AH/12V battery was chosen to adequately carry the current safely.

The time that the 200AH/12V battery will run is given by equation (8)

$$= \underline{200AH} \times 0.85 = 3.7hrs \text{ (3hrs 42 minutes)}$$

For 5 batteries connected in series, total time is given by 3.7 x 5 = 18.5 (18hrs, 30 minutes) considering losses, the batteries can run for 16 hours with the base Load connected

(d) Design of the photovoltaic array

(i) The battery charge is given by equation (9)

Where I_{max} = 200AH

I_{charge} = 10 x 200 = 20A

Since the 5 batteries are in series, the same charging current flows through them.

Charging voltage required = 15v x 5

= 75v

No of solar panels needed is given by equation (10)

$$= \frac{7.5}{2.4} = 3.125$$

No of solar panels = 3panels in series (voltage charging)

Current produce by 1 solar panel

$$I_{Sol} = \frac{P_S}{V_S} = \frac{200}{24} = 8.3A$$

No of panels required to produce

20A current (charging current)

$$Is = \frac{20}{8.3} = 2.4 \text{ (3 panels in parallel)}$$

For efficiency, 4 panels are used to increase the current to 28.3A (variation in Sun intensity)

Total number of panels needed to charge the batteries = 3x4 = 12 panels. (3 in series and 4 in parallel) Fig.3 shows the connection of the solar panels

(ii) To charge and carry the base load

From computation to carry the base load with 5KVA inverter, current needed is 46A. To charge the batteries, current needed is 28.3A.

Total current needed = 46+28.3 = 74.3A

No of panels require in parallel

$$= \frac{74.3}{8.3} = 8.9 = 9 \text{ panels in parallel}$$

Total number of panels required

= 9x3 = 27 panels

3 panels in series gives the charging voltage

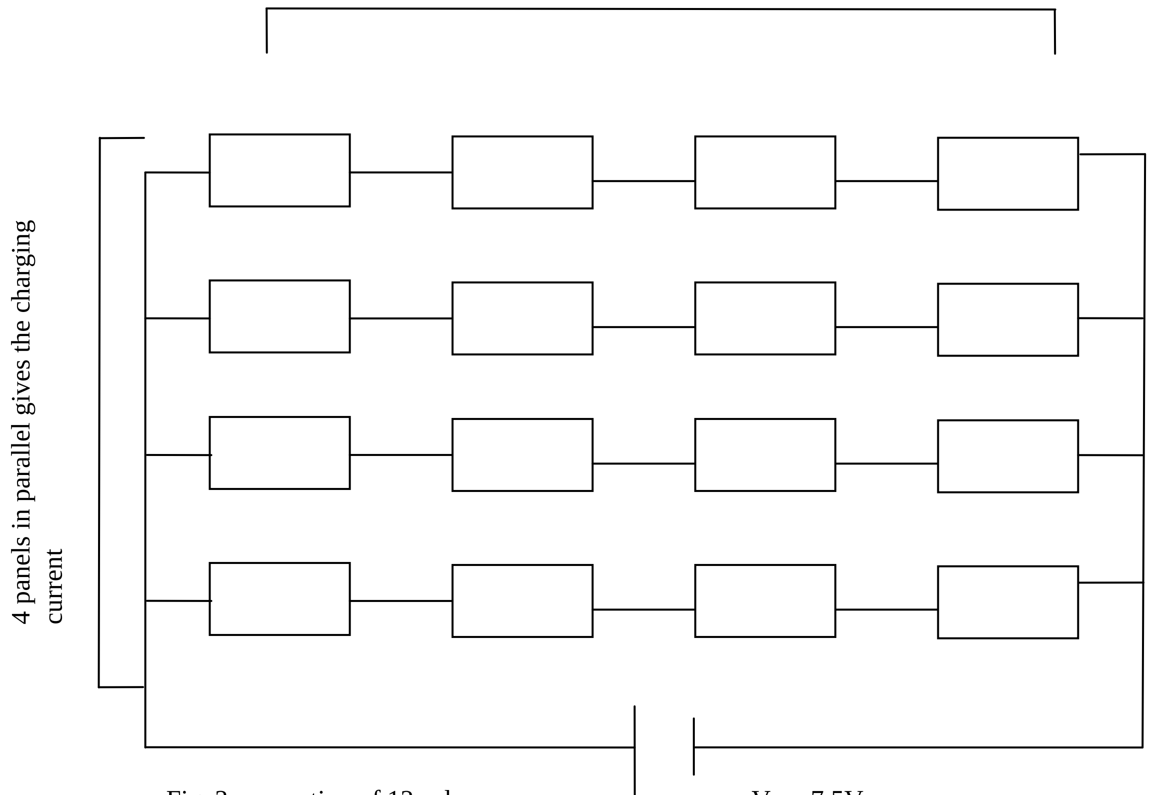

Fig. 3 connection of 12 solar panels for charging

V_C =7.5V
I_C = 28.3A

(e) Charge controller

A charge controller of 40A – 80A was chosen for this circuit

(f) Cost analysis

The cost analysis is shown in Table 4

Fig.4: Classroom of a secondary school

Results and Discussions

There are twenty-nine Nursery/Primary schools and twenty- two secondary schools in Auchi. The questionnaires that were distributed to them were collected from them after they have filled them. They were then collated and analyzed in order for results to be drawn from them.

The survey show that Power Holding Company of Nigeria Limited (PHCN) is the major source of power supply but they hardly get power from them. The lack of power supply affect learning in the schools in that most of the classes do not have fans as shown in plate 1. The lack of electricity also affects the sanitary condition of the schools because without electricity, they can not pump water for the toilet facilities in the schools. The survey also shows that electricity is needed for lighting and powering some equipment in offices and laboratories during some laboratory practicals. Some schools that has boarding house facilities also need electricity at night. From the energy audit survey, the schools need an average of between 26.36kwh to 20.72kwh of energy to solve their electricity need. Note that the above values represent the peak load i.e when all the equipment are working while the base load i.e when some of the equipment are put off can be as low as 3.76kwh. The above energy need can be met by using photovoltaic system as an alternative to electricity from the Power Holding Company of Nigeria Limited (PHCN).

Conclusion

The average cost of buying and installing a photovoltaic system in a typical secondary school in Auchi area of Nigeria is three million, six hundred and nineteen thousand naira (N3,619,000) as can be observed in appendix 2. Similarly, the average cost of buying and installing a photovoltaic system in a typical nursery/primary school in Auchi area of Nigeria is two million, two hundred and eighty eight thousand Naira (N2,288,000) as shown in appendix 4. Although the above results were obtained in Auchi area of Nigeria, with slight modifications, they can be apply to any part of Nigeria.

The initial cost of the photovoltaic system for the various schools are favourable when compared to the cost of either buying, maintaining and running a generator or paying electricity bills for about 15 years. It is important to know that these are the costs for a stand-alone photovoltaic systems and the systems will be guaranteed to supply electricity for above 15 years for the batteries and inverters, and above 35 years for the solar panels. Solar power can be used as alternative source of energy for primary and secondary schools, not only because of their economic advantages over the conventional power supply but also because they are noiseless, environmentally friendly, not sporadic or subjected to load shedding especially in a country like Nigeria.

Appendix A: cost analysis for a typical nursery/primary school in Auchi.

S/N	Item	Qty	Rating	Unit cost (N)	Amount (N)
1.	Inverter	1	5KVA	100,000	100,000
2.	Battery	5	12v, 200AH	40,000	200,000
3.	Solar panel	27	200w/24v	65,000	1,755,000
4.	Charge controller	1	40-80A	25,000	25,000
5.	Sub-total				2,080,000
6.	Miscellaneous and installation (10%)				208,000
7.	Total				2,288,000

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