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ECONOMIC ANALYSIS
OF
ELECTRICAL DISTRIBUTION
IN
LARGE BUILDINGS

by

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ABSTRACT

Different methods available for electrical distribution in large indoor establishments have been evaluated on a cost minimization basis, keeping in view the electrical performance of voltage drop and line losses.

Choice of voltage provided by the supply authority is also examined on economic grounds. Each method of distribution is analysed on the accepted system voltages.

After a survey, an example of a fifteen storey commercial office building has been chosen for detailed economic study to formulate recommendations applicable to a wide range.

It has been concluded that the 600 volt bus duct system provides the best answer inasmuch as it entails lowest voltage drop and minimum distribution losses, besides proving to be the most economical in capital investment.

It is hoped that the electrical consulting engineer would find practical use for this detailed analysis.

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CHAPTER 1

INTRODUCTION

The electrical installation in any large building - commercial or industrial - consists of lighting, motor control and distribution in addition to the actual apparatus which utilizes electrical energy. When designing each of these systems, various alternative choices are available for materials, system arrangement and design procedure.

Many possible alternatives available for electric systems require proper evaluation. It is possible to analyze some methods for different situations and to find that one method which may not always be the lowest in cost offers better performance in service. The most economical, moreover, may not be a practical solution in certain situations. It is, therefore, necessary to carry out detailed economic study to establish optimum standards.

1.2 Lighting

In order to design lighting systems, the important decision is the source of light including the luminaire, type of lamp and control for the light. The choice normally is made on the basis of level of illumination, colour rendition and visual task.

Light is produced predominantly by incandescence and gaseous discharge including fluorescence. The incandescent lamp entails low capital cost because of its simplicity of construction and circuitry; however, it has low luminous efficacy approximately 16 lumens per watt. It therefore is used mostly for lighting small areas particularly residential buildings.

The gaseous discharge lamp produces light as a result of a

current through a gas or vapour under pressure. Once the arc is established, the current through the gas increases without control, hence a device called ballast must be used to control the current through the lamp.

The medium pressure mercury lamp used for lighting applications operates at about 1.7 to 10 atmospheres of pressure. It has high luminous efficacy about 3 times that of the incandescent lamp or 40 lumens per watt. Sport stadiums, convention halls and other large areas require this type of point source of lighting for disbursement over a wide range.

The fluorescent tube operating as a gaseous discharge lamp under low pressure provides a uniform source of light over a surface. Its luminous efficacy is four times that of the incandescent lamp or 62 lumens per watt. This type is useful for lighting large work areas such as offices, shops and factories.

On perusal of the foregoing, it may be seen that the choice of lamp and its accessories is dictated by the use to which the lighted space is subjected, and standard products are available for various applications.

1.3 Motor Control

Motors installed in different areas of large buildings are controlled through their starters and switches located either nearest to the process and the motor operating it or at the centralized control centres. Individual control of each and every motor may be necessary in the case of very large installations, but the centralized method provides a good way of co-ordinating the distribution system short circuit ratings to ensure a high degree of system reliability.

1.4 Distribution System

The field of distribution in the electrical installation of large buildings offers choice in supply voltage and also different methods of wiring. Both are interdependent to some extent which makes the design of distribution systems comparatively more complex. Detailed economic study to establish optimum design standards has not been undertaken in the past. There is little published material available on this subject. Therefore, this work has been taken up and a comprehensive treatment is given in the following chapters.

CHAPTER 2

DISTRIBUTION

2.1 Distribution Systems

The electrical system between the main transformer provided by the supply authority and the utilization point where electricity is consumed is the distribution system.

Generally speaking, there are two fundamental types of distribution - radial and network. Radial distribution literally means that it has a single path of electrical flow to the load while the network has more than one simultaneous path to reach the utilization point.

Since the radial system is most commonly used, in all types of commercial and residential buildings for economic reasons, as well as, many medium-size industries, it forms the basis of analysis in the subject presentation.

2.2 Supply Voltage

Except for a major industrial load, the supply authority provides a limited choice of voltages to the user. In some large metropolitan areas, supply at 5 kv is offered along with low voltage systems at 600 volts, 480 volts, 240 volts and 208 volts. Of these, 600 volt and 208 volt systems are in wide use. This detailed analysis is limited, therefore, to 600 volt and 208 volt systems.

The basic reason for 600 volt and 208 volt systems being widely accepted is that most of the load in large buildings can be directly connected at these voltages. Motor sizes encountered in such installations operate efficiently at 550 - 600 volts. The lamps and office equipment normally are designed to operate at 120 volts obtained from

208 volts, 3 phase supply. The following alternatives have, therefore, been considered:

- (a) Scheme A is defined as providing both the system voltages in the installation - 600 volts for the motors and 208/120 volts for light and power. If the supply authority provides 600 volts only, then the 120 volt load is provided through a 600 - 208/120 volt step-down transformer. In case of 208 volt supply, a 208 - 600 volt step-up transformer would be required to meet the motor load.
- (b) Scheme B is defined as providing entire distribution at 600 volts and provision of small dry type 600 - 208/120 volt transformers in different sections of the installation for supply to 120 volt loads. 347 volt ballasts are now available for use with fluorescent lamps in industrial and commercial establishments. 120 volts supply is required for office equipment and incandescent lighting only.
- (c) Scheme C provides the distribution at 208/120 volts, on the basis that the motors are specified to receive this voltage.

2.3 Wiring Methods

The following methods of wiring are commonly used. Each of them is analyzed for operation at the voltage systems described in 2.2 (a), (b), and (c) above.

- (a) Bus Duct consists of three or four bus bars mounted in a rectangular enclosure which is ventilated or totally enclosed. It is used as a main feeder from the transformer secondary to the main switchboard and from the main switchboard as a plug-in

duct allowing connections to different sections of the building on its way to the furthest load point.

- (b) Wires in Conduit: Three or more wires suitably insulated for operating voltage and placed in a raceway, metallic conduit or tubing, are taken from the main switchboard directly to various loads in the building. Usually one conduit containing the required number of insulated wires is taken to the branch circuit panelboard on each floor in a multi-storey building or to each of the conveniently divided sections in any large installation.
- (c) Power Cables: Single or multi-conductor wires are individually insulated and mechanically strengthened with metallic sheaths to form a composite power cable. This is used in place of wires in conduit for supply of electric power to different sections of the large building.

These cables were initially developed for installation in mines and underground distribution where heavy mechanical protection is necessary. For buildings, however, outer metallic sheaths can be made of aluminium. Because of adequate mechanical protection and convenience of bending, corrugated aluminium sheathed cable has been widely accepted for indoor distribution in large buildings.

2.4 Aluminium Conductors

Copper conductors normally used for electric distribution in the past gradually are being replaced by an electrolytic grade aluminium meeting the requirements of various national standards. A brief description of the reasons for the preference for aluminium therefore would be

appropriate.

- (a) Cost Savings: The cost of aluminium conductors is lower than comparable copper conductors (having the same current carrying capacity).
- (b) Availability: Aluminium is one of the most abundant metals in the earth's crust. Availability of raw materials needed for extraction of aluminium exceeds by far that of resources of copper.
- (c) Light Weight: The weight of aluminium conductor is lower than a comparable copper conductor; hence, ease of handling is a benefit during installation, particularly on large sizes of conductors.

In general, the over-all diameter of aluminium conductors is larger than a comparable copper conductor (having the same ampacity). This factor is to be considered in choosing cable trays or conduits.

Without going into further details of comparison between aluminium and copper conductors, acceptance of aluminium wires or cables in main distribution is recognized and aluminium is therefore the basis of analysis in this presentation.

2.5 Voltage Drop and Loss Considerations

Consideration of voltage drop is necessary to assess the quality of service on a distribution system. If the quality of service does not meet the recommended voltage limits, a larger size of wire or cable must be used. Conductor sizes used in this study are computed on

the basis that the maximum voltage drop may not exceed 5 percent.

Any study on economics of the system must similarly take into account the losses that occur while current passes through the feeders. Necessary calculations, therefore, have been made and their effect taken into consideration while reaching the conclusion.

CHAPTER 3

PROCEDURE

3.1 Introduction

This chapter deals with the detailed method commonly adopted by the electrical consulting engineer to design the electrical distribution in large buildings, and the procedure followed by the electrical contractor to estimate the cost of materials and labour.

Length of wires and conduit, power cables or bus duct to different sections are discussed. Sources of material prices and labour costs are described and the procedure for voltage drop and loss calculations is indicated.

3.2 Design Method

The architect or planner working on the development for which electrical design is required prepares the detailed layout of all areas. The electrical consulting engineer computes the electrical load on the basis of the use for which each area is planned. Both consult each other and decide on the location of distribution panelboard for each area in relation to the loads therein as well as the route of the main supply line.

In the case of multi-storey structures, the service core of the building is placed centrally. The electrical room on every floor is usually located alongside or near elevators. When dealing with a horizontal development, the electrical main supply and distribution panelboards are located in relation to the concentration of loads in different areas of the building.

3.3 Distances

The supply authority provides the electric supply at the building

corner where the transformer or transformers and the main distribution panelboard are located. Length of wiring is then computed from the main panelboard to all the electrical rooms on various floors in the high-rise building or in different sections of the horizontal development.

3.4 Conductor Sizes

After computing the loads and their distances from the main panelboard, conductor sizes are determined in accordance with the requirements of the Canadian Electrical Code, Part I (tenth edition) CSA Standard C 22.1 of 1969.

3.5 Cost of Materials and Labour

The electrical contractor maintains detailed catalogues and price lists issued by most of the manufacturers. Lowest trade prices available from them are therefore taken into account while pricing a job.

"Manual of Labour Units" issued by the Research Department of the National Electrical Contractors' Association, Inc., of Washington, D.C., forms the basis of labour costs.

In Winnipeg, a licensed electrician with good experience receives \$5.00 per hour. Taking into account the supervision and overhead, the rate of \$5.75 for each man hour or labour unit is used in this economic analysis.

3.6 Voltage Drop and Loss Calculations

Conductor manufacturers provide voltage drop curves or tables in their catalogues with a view to guide users on choice of conductor size. These take into account different types of insulation and are computed from readings taken in actual experiments conducted in service conditions.

Distribution loss is calculated from the basic principle of

$I^2 R$.

CHAPTER 4

PARAMETERS

4.1 Typical Building

The economic investigation of the different methods of indoor distribution can be undertaken in relation to the very wide range of large buildings in use for various purposes. It is necessary in this study to limit the design problem to a representative application. A typical building is, therefore, chosen after a brief survey of practice.

In metropolitan Winnipeg, the present trend for office buildings is towards the large high-rise tower concept. It has been found that modern commercial offices of average size are planned in 12 to 20 storey buildings with floor area varying from 10,000 to 15,000 square feet per floor.

In order to secure maximum use of elevators, these are located in the approximate centre of the building. The service core consisting of elevators, lobby and electrical room forms about 20% of the floor area in the case of prestige buildings. It can be safely reduced to 12% for maximum utilization of the available space.

Based on the foregoing observations, a typical office building 15 storeys high, and each floor having an area of 12,000 square feet has been chosen to limit the problem to a representative application. Electrical loads to adequately service all sections of the building are computed as follows.

4.2 Electrical Loads

- (a) Light and Power; A commercial office normally needs 4 watts per square foot for lighting and 1 watt per square foot for typewriters, calculating machines and similar office equipment.

Thus, a 12,000 square foot floor would require 60 kw. Allowing for future load growth and abnormal conditions in particular cases, provision is made for an extra 25% of the normal load. 75 kw or 200 amperes at 208/120 volts is estimated as the standard load for every floor.

- (b) Air conditioning Plant: For the size of building under consideration, a load of 460 kw would be required for the chiller. This plant would usually be located on the roof.
- (c) Air-supply Fans: A total fan load of 200 hp divided between three or four locations would be required for air-circulation. It is proposed that a 50 hp fan be installed at each of the 15th, 11th, 7th, and 3rd floors.
- (d) Water Pumps: Two pumps each of 20 hp would be required at the roof for the cooling tower attached to the air-conditioning plant. In addition, pumps with a total capacity of 40 hp would be needed at the basement to boost water supply pressure for normal and fire purposes.
- (e) Heating and Miscellaneous Loads: Four pumps of different sizes totalling 25 hp would be needed for running boilers and hot water circulation. Another load of 25 hp would be required for elevators, exhaust fans, control air pump and other miscellaneous equipment. Provision of 50 hp, therefore, is made for these loads at the basement.

4.3 Distribution of Loads

Based on all the loads detailed above, the following distribution in the fifteen storey building, adopting various alternatives discussed in

paragraph 2.2, pages 7 and 8 , is proposed.

	<u>Scheme A</u>	<u>Scheme B</u>	<u>Scheme C</u>
Roof	600 amperes at 600 volts	600 amperes	1500 amperes
15th floor	(60 amperes at 600 volts) ((200 amperes at 120 volts)	135 amperes	400 amperes
14th floor	200 amperes at 120 volts	75 amperes	200 amperes
13th floor	200 amperes at 120 volts	75 amperes	200 amperes
12th floor	200 amperes at 120 volts	75 amperes	200 amperes
11th floor	(60 amperes at 600 volts) ((200 amperes at 120 volts)	135 amperes	400 amperes
10th floor	200 amperes at 120 volts	75 amperes	200 amperes
9th floor	200 amperes at 120 volts	75 amperes	200 amperes
8th floor	200 amperes at 120 volts	75 amperes	200 amperes
7th floor	(60 amperes at 600 volts) ((200 amperes at 120 volts)	135 amperes	400 amperes
6th floor	200 amperes at 120 volts	75 amperes	200 amperes
5th floor	200 amperes at 120 volts	75 amperes	200 amperes
4th floor	200 amperes at 120 volts	75 amperes	200 amperes
3rd floor	(60 amperes at 600 volts) ((200 amperes at 120 volts)	135 amperes	400 amperes
2nd floor	200 amperes at 120 volts	75 amperes	200 amperes
1st floor	200 amperes at 120 volts	75 amperes	200 amperes
Basement	100 amperes at 600 volts	100 amperes	270 amperes

4.4 Distances

Distance from the distribution mains and supply transformer
at the building corner where the supply authority normally provides the

electric connection is computed to the electrical room at every floor.

Since the service core of the building is placed centrally, the electrical room in the basement would be at an approximate distance of 100 feet from the distribution mains (the floor being 12,000 square feet or 120' x 100').

Vertical distance between consecutive floors is normally ten feet. Keeping in mind that the motor control centre on the roof may be located at a distance away from the central core, lengths of conductors from the distribution mains to various floors are computed as indicated hereunder:

Roof	300 feet.
15th floor	260 feet.
14th floor	250 feet.
13th floor	240 feet.
12th floor	230 feet.
11th floor	220 feet.
10th floor	210 feet.
9th floor	200 feet.
8th floor	190 feet.
7th floor	180 feet.
6th floor	170 feet.
5th floor	160 feet.
4th floor	150 feet.
3rd floor	140 feet.
2nd floor	130 feet.
1st floor	120 feet.
Basement	100 feet.

4.5 Computation

In line with the provisions of the Canadian Electrical Code, Part I (tenth edition) CSA standard C22.1 of 1969, conductor sizes were established to carry the load detailed in paragraph 4.3 across distances indicated in paragraph 4.4. Detailed calculations for alternative methods of wiring under each of the three voltage systems are given in Appendices I to III to show voltage drop and distribution losses as well as cost of materials and installation labour.

CHAPTER 5

DISCUSSION

5.1 Application of Analysis

After examining each alternative scheme separately for different methods of wiring to distribute electric power in the typical building to meet required loads, the results have been compared. These are discussed here to develop broad recommendations for design of electrical distribution in large buildings.

5.2 Cost Comparison

The results of detailed cost calculations shown in Appendices I to III are summarized hereunder:

		<u>Wires in Conduit</u>	<u>Power Cable</u>	<u>Bus Duct</u>
Scheme "A"	Materials	\$ 31,970.92	\$ 28,501.57	\$ 33,666.51
600 volts &	Labour	8,393.56	4,719.03	4,115.85
120/208 volts	Total Cost	40,364.48	33,220.60	37,782.36
Scheme "B"	Materials	\$ 23,692.59	\$ 22,664.70	\$ 22,317.25
347/600	Labour	4,988.41	2,326.16	2,061.95
volts	Total Cost	28,681.00	24,990.86	24,379.20
Scheme "C"	Materials	\$ 55,536.05	\$ 46,142.40	\$ 29,948.00
120/208	Labour	10,790.74	5,149.13	2,654.78
volts	Total Cost	66,326.79	51,291.53	32,602.78

Scheme "A" In this case where two voltage systems are considered, the materials are costliest on using bus duct. Labour cost of installing wires in conduit is about double of that involved in either of other alternatives, with the result, the total cost of adopting wires in conduit is the highest.

Scheme "B" In this case where the insulation is utilized to the maximum extent, cost of materials is marginally lower on considering power cable or bus duct. Labour cost in installing wires in conduit is more than

double of that involved in either of the other alternatives, with the result total cost of adopting wires in conduit is the highest.

Scheme "C" In this case where the lowest voltage is used with the consequent increase in size of conductors, cost of materials is abnormally high in using wires in conduit. Of the other two alternatives, cost of bus duct is considerably lower than that of power cable. Differences in labour costs are more pronounced, with the result, the total cost of adopting wires in conduit is more than double of that considering bus duct. Total cost of using power cables is also very high in relation to the bus duct.

It is evident that the most commonly used method of wires in conduit entails highest total cost. Comparing it with the power cables, the labour for installation is approximately double that required to install the latter. This is because the conduits are firstly laid along the route of distribution and then the insulated wires are drawn through them. On the other hand, a single operation of drawing the power cables is sufficient to install the feeders. Cost of materials is also higher, as the insulated conductor and its protective cover (conduit) are separate.

Comparing the costs of bus ducts: these are higher in the case of Scheme "A" which involves two different voltage systems at which power is carried to various sections of the establishment. In the case of 600 volts distribution (Scheme "B"), the costs of bus duct and power cables are comparable. The bus duct provides the lowest cost when Scheme "C" covering 120/208 volts distribution is considered. This is primarily because of inherent higher ampacity of bus ducts. On reducing the voltage

from 600 volts to 120/208 volts, the size of wires in conducting power cables increases considerably and the size of bus duct does not increase to the same extent.

Besides the costs, other criteria are required to be examined. The voltage drop and loss considerations as well as space requirements, accessibility, etc., are discussed in the following paragraphs.

5.3 Voltage Drop

The following figures were obtained on calculating maximum percentage drop for the three schemes using different methods of distribution:

	<u>Wires in Conduit</u>	<u>Power Cables</u>	<u>Bus Duct</u>
Scheme "A"	2.92 %	4.50 %	2.61 %
Scheme "B"	1.29	1.62	1.08
Scheme "C"	2.81	5.00	2.27

The higher voltage drop in power cables is attributed to the use of single conductor cables offering higher ampacity in relation to three conductors of the same size placed in one conduit. In the case of Scheme "B", multi-conductor cables have been found to be adequate, with the result that the voltage drop is comparable.

5.4 Loss Consideration

Detailed calculations given in the Appendices I to III produce the following distribution losses given in kilowatts:

	<u>Wires in Conduit</u>	<u>Power Cables</u>	<u>Bus Duct</u>
Scheme "A"	19.450 Kw.	29.309 Kw.	18.227 Kw.
Scheme "B"	10.967	13.535	7.905
Scheme "C"	21.709	42.854	16.627

These figures follow the same pattern as for the voltage

drop. Comparison of the three schemes shows that Scheme "B" - 600 volts system entails lowest voltage drop as well as distribution losses.

5.5 Choice of Voltage

The basic considerations such as capital cost and performance characteristics have been examined in the foregoing paragraphs. It is clear from cost estimates given in paragraph 5.2 that the 600 volts system (Scheme "B") requires lowest initial investment in cost of materials as well as installation labour, irrespective of the method of wiring that may be adopted.

The voltage drop and loss considerations discussed in paragraphs 5.3 and 5.4 show that the operating expenses also for the distribution would be the lowest in case of Scheme "B", irrespective of the method of wiring that may be adopted.

On perusal of the detailed economic analysis as above, it is clear that the 600 volts system is the best on the basis considered. The principle of transmitting electrical energy at the higher voltage advantageously is applicable to distances encountered in the wiring of buildings also.

In metropolitan areas where electric loads considered in this analysis are applicable, the supply authority allows some choice of supply voltage to the user. In most cases, the electrical engineer should select 600 volts, 3 phase, 4 wire supply and adopt Scheme "B".

It is, however, possible in certain cases that only one of the two systems (347/600 volts or 120/208 volts) is available or desirable. If 120/208 volt system has to be used, heavy motor loads could be supplied through 208 - 600 volts step-up transformers, and Scheme "A" considered

in comparison to Scheme "C" where the alternative of bus duct offers an economical solution.

5.6 Power Cables versus Bus Duct

Having decided the system voltage, it is necessary to evaluate various methods of wiring to obtain the optimum design for electrical installation in large buildings. The commonly used method of wires in conduit should be eliminated because of high cost of labour, as discussed in paragraph 5.2 above. The remaining two methods - power cables and bus duct are, therefore, analysed from the points of view of space requirements, accessibility, etc.

- (a) Space Requirements: On perusal of single line diagrams (drawings 3, 6 and 9), it may be seen that main distribution panelboard/s are required near the supply authority transformer if power cables are used to carry power to every floor. This necessitates a large electrical room.

Furthermore, power cables are necessarily secured to a wall, roof or other fixed surface for proper attachment and they have to be separated from each other by at least one diameter. Therefore, spacious area is required to accommodate them, particularly near the mains distribution panelboard. As the distance from the mains increases, the number of cables for which space is needed decreases. The reason is that each floor or section of the building takes a feeder for electrical requirements there.

On the other hand, bus duct, which is a compact rectangular box measuring from $3\frac{1}{2}$ " to $8\frac{1}{2}$ " in thickness and $9\frac{1}{2}$ " to 21" width, requires limited space throughout its length.

At the supply authority transformer secondary, only a standard fitting connects the duct, requiring no special accommodation.

In case of commercial buildings, particularly near the city core, space is high revenue and the owner likes to save it as much as possible for leasing the same profitably. Bus duct therefore commands a definite advantage on this score.

- (b) Accessibility: For the purpose of maintenance and repair, it is necessary for the bus duct to be fully accessible throughout its length. Bus duct has therefore to be installed in electrical rooms one above the other in case of high-rise buildings. Horizontal development would incorporate a separate and enclosed passage for the bus duct to be accessible at all points.

In the case of power cables, these can be run in crawl spaces, corners and other inaccessible areas. If the cable runs are especially laid to utilize otherwise unusable space, extra length may entail higher capital cost. Otherwise the cable terminus only is required for connection to the load or floor distribution panelboard. Thus use of power cables provides flexibility not possible with the bus duct.

Normally the architect prepares detailed plans to the specifications of the owner, and the electrical engineer has to design the distribution system to suit available facilities, meeting all requirements of the load spread across the establishment. It is therefore not always possible to adopt the bus duct.

- (c) Load Increase: Though original design must make provision for possible future growth, it may be necessary to connect extra loads in unforeseen circumstances. In such an eventuality bus duct provides inherent capacity allowing plug-in facilities. If power cables had been adopted, extra connections would have to be taken right from the mains, necessitating separate cable runs.
- (d) Voltage Drop and Loss Considerations: On perusal of tabulations in paragraphs 5.3 and 5.4 (pages 18 and 19), it is clear that the bus duct entails the lowest drop and the minimum loss. Savings seem to be small but their effect over a long period during which the system is expected to operate would not be insignificant.

From the foregoing discussion on power cables as against bus duct, it is evident that the preference has to be accorded to the bus duct, mainly on the basis of smaller space requirements and better performance in voltage drop and distribution losses. Cost comparison also indicates that marginally lower investment is needed on both the system voltages.

This analysis produces evidence to show that the bus duct has advantages irrespective of the supply voltage provided by the supply authority, though savings are higher when 600 volts supply is available.

CHAPTER 6

CONCLUSIONS

6.1 Summary

Since distribution forms the most important part of electrical installation in large buildings, nine alternatives to reflect three commonly accepted voltage systems and the three wiring methods available to transmit electrical energy to various sections of the buildings were evaluated to develop broad recommendations for wide application.

It has been conclusively proven that the 600 volts system in comparison to 120/208 volts system and two-tier distribution at 600 volts for heavy loads and 120/208 volts for lighting and power is the best from the standpoints of initial capital investment, as well as, voltage drop and loss considerations. This conclusion is based on use of any of the three wiring methods—bus duct, power cables or wires in conduit. The basic reason underlying the conclusion is that all materials are utilized to the maximum extent when 600 volts system is used.

Of the available wiring methods, it has been shown that the bus duct is the most economical in total cost. When cost of materials and installation labour are separately considered, the bus duct entails lowest investment under each head on adopting single systems either 600 volts or 120/208 volts. In case of two-tier distribution at 600 volts for heavy loads and 120/208 volts for lights and power, cost of two bus ducts is understandably higher than that involved in power cables or wires in conduit. Cost of installing bus ducts is, however, lowest of the three with the result, the total cost of the two bus ducts is lower than that involved in the other two methods.

Economic analysis carried out in this study, therefore, concludes

that 600 volts single bus duct system offers the best solution from among nine alternatives considered. In case the supply authority provides a 120/208 volts supply only, bus duct is still the best method to distribute the entire load to different sections of the building on account of low material cost, as well as, installation labour. Consideration to raise the distribution voltage to 600 volts for heavy motor loads should be avoided, as it entails two different voltage systems and, therefore, two bus ducts to supply the same load.

If, however, space limitations do not provide accessibility for operation and maintenance of the bus duct system, corrugated aluminium sheathed aluminium cables should be adopted. In this case, transformation of the power required for motors and other heavy loads to 600 volts is worthwhile, as it reduces the size of required cables resulting in considerable economy.

This study also shows that the commonly used method of wires in conduit is the costliest in installation labour. Cost of materials is also high considering single systems of 600 volts or 120/208 volts. When two-tier distribution involving both voltages is considered, bus duct costs more than wires in conduit. Since labour costs are highest for wires in conduit for two-tier distribution also, the total costs comparing all the three methods do not justify use of wires in conduit for the conditions considered.

6.2 Recommendations

- (a) Obtain 600 volts 3 phase 4 wire supply and plan a single bus duct run for the entire distribution.
- (b) If 600 volts supply is not available and 208/120 volts supply is

provided, bus duct is still the best for supplying all loads on a single system.

- (c) If it is not possible to run fully accessible bus duct, corrugated aluminium sheathed aluminium cables should be designed for the following conditions:
 - (i) 600 volts supply: Cables may be used from the main distribution panelboard to every section of the establishment, and 600 - 208/120 volts step-down transformers located nearest to the load.
 - (ii) 208/120 volts supply: A step-up 208 - 600 volts transformer may be installed at the distribution mains for motors and other heavy loads; and supply taken to each load centre through separate cables.
- (d) Distribution by means of wires in conduit should be avoided on account of high labour cost.

Appendix I

SCHEME A(600 volt and 208/120 volt systems)I.1 Unit Rates

The following unit rates were obtained for the cost study:

TYPE R90 ALUMINIUM WIRES

	Cost of Materials	Installation Labour
	Rate per 1,000 feet	
500 MCM	\$1,301.00	58 Manhours
250 MCM	660.00	45
#1 AWG	260.00	23
#4 AWG	132.00	18

CONDUITS FOR THE ABOVE WIRES

	Rate per 100 feet	
3" Rigid Conduit	\$ 259.15	18.50 Manhours
2½" Rigid Conduit	193.60	15.50
1½" EMT	36.85	5.50
1¼" EMT	29.80	4.75

TYPE R90 ALUMINIUM SHEATHED CABLES
WITH ALUMINIUM CONDUCTOR/S

	Rate per 1,000 feet	
750 MCM	\$2,592.00	85 Manhours
4/0 AWG	968.00	45
3 conductors #1 AWG	1,124.00	42
3 conductors #4 AWG	698.00	40

Scheme A (Continued)MAIN DISTRIBUTION PANELBOARD

consisting of:

1 - 1,500 ampere, 600 volt, 3 phase, 4 wire breaker	\$2,492.00
1 - 800 ampere, 600 volt, 3 phase, 4 wire breaker	758.21
1 - 750 kva, 600-208/120 volt transformer	6,624.00
15 - 225 ampere, 208 volt, 3 phase, 4 wire breakers	2,856.81
1 - Factory assembled panel for 208/120 volt distribution	278.30
1 - 600 ampere, 600 volt, 3 phase, 3 wire breaker	608.85
4 - 60 ampere, 600 volt, 3 phase, 3 wire breakers	323.68
1 - 100 ampere, 600 volt, 3 phase, 3 wire breaker	80.92
1 - Factory assembled panel for 600 volt distribution	440.00
Total cost of materials	\$14,462.77
Installation labour	<u>186 Manhours</u>

BUS DUCTS WITH ALUMINIUM BUS BARS
AND THEIR ACCESSORIES RATED AT 347/600 VOLTS

	Rate per foot	
600 ampere, 3 pole feeder type	\$ 10.50	0.45 Manhour
800 ampere, 3 pole plug-in type	15.50	0.50
600 ampere, 4 pole full neutral, plug-in type	17.00	0.60
2500 ampere, 4 pole full neutral, plug-in type	60.50	1.00
Reducer from 800 amperes bus duct each	86.00	4.50
Reducer from 2500 amperes bus duct each	274.00	12.00
600 ampere, 3 pole 3 wire bus plug (C.B.)	761.50	8.00
60 ampere, 3 pole 3 wire bus plug (C.B.)	99.00	1.95
100 ampere, 3 pole 3 wire bus plug (C.B.)	99.00	3.00
200 ampere, 3 pole 4 wire bus plug (C.B.)	232.00	4.70

I.2 Voltage Drop and Loss Calculations

(a) ALUMINIUM WIRES IN CONDUIT

	Feeder Capacity Amperes	Line to Line Voltage Drop volts	Maximum Loss kw
Roof feeder	600	5.260	3.156
15th Floor (600 volts)	60	14.040	0.842
15th Floor (120 volts)	200	6.084	1.217
14th Floor	200	5.850	1.170
13th Floor	200	5.616	1.123
12th Floor	200	5.382	1.076
11th Floor (600 volts)	60	11.880	0.713
11th Floor (120 volts)	200	5.148	1.030
10th Floor	200	4.914	0.983
9th Floor	200	4.680	0.936
8th Floor	200	4.446	0.889
7th Floor (600 volts)	60	9.720	0.583
7th Floor (120 volts)	200	4.212	0.842
6th Floor	200	3.978	0.796
5th Floor	200	3.744	0.749
4th Floor	200	3.510	0.702
3rd Floor (600 volts)	60	7.560	0.454
3rd Floor (120 volts)	200	3.276	0.655
2nd Floor	200	3.042	0.608
1st Floor	200	2.808	0.561
Basement (600 volts)	100	3.650	0.365
Total maximum loss			<u>19.450</u>

Maximum voltage drop occurs in 15th floor (120 volts) feeder.

$$\text{Maximum percent drop: } \frac{6.084}{208} \times 100 = \underline{2.92\%}$$

I.2 Voltage Drop and Loss Calculations (Continued)

(b) CORRUGATED ALUMINIUM SHEATHED CABLES

	Feeder Capacity Amperes	Line to Line Voltage Drop volts	Maximum Loss kw
Roof feeder	600	9.72	5.832
15th Floor (600 volts)	60	14.04	0.843
15th Floor (120 volts)	200	9.36	1.872
14th Floor	200	9.00	1.800
13th Floor	200	8.44	1.728
12th Floor	200	8.28	1.656
11th Floor (600 volts)	60	11.88	0.713
11th Floor (120 volts)	200	7.92	1.584
10th Floor	200	7.56	1.512
9th Floor	200	7.20	1.440
8th Floor	200	6.84	1.368
7th Floor	60	9.72	0.583
7th Floor	200	6.48	1.296
6th Floor	200	6.12	1.224
5th Floor	200	5.76	1.152
4th Floor	200	5.40	1.080
3rd Floor (600 volts)	60	7.56	0.454
3rd Floor (120 volts)	200	5.04	1.008
2nd Floor	200	4.68	0.936
1st Floor	200	4.32	0.864
Basement	100	3.65	0.365
Total maximum loss			<u>29.309</u>

Maximum voltage drop occurs in 15th floor (120 volts) feeder.

$$\text{Maximum percent drop: } \frac{9.36}{208} \times 100 = \underline{4.5\%}$$

I.2 Voltage Drop and Loss Calculation (Continued)

(c) BUS DUCTS

(i) 600 volt bus duct

Length of Section Feet	Estimated Maximum Section Current Amperes	Line to Line Voltage Drop Volts	Maximum Loss kw
100	800	4.00	3.200
40	715	1.20	0.858
40	664	1.10	0.731
40	613	1.00	0.613
40	562	0.96	0.540
40	510	0.90	0.459
Voltage drop in 600 volt bus duct:		----- 9.16 or 1.527%	-----
Maximum loss in 600 volt bus duct:			<u>6.401 kw</u>

(ii) 208/120 volt bus duct

120	2,500	3.450	8.625
10	2,333	0.270	0.630
10	2,167	0.250	0.542
10	2,000	0.225	0.394
10	1,833	0.215	0.300
10	1,667	0.180	0.235
10	1,500	0.170	0.213
10	1,333	0.160	0.152
10	1,167	0.130	0.115
10	1,000	0.115	0.083
10	833	0.100	0.083
10	667	0.070	0.047
10	500	0.050	0.025
10	333	0.035	0.012
10	167	0.015	0.003
		-----	-----

Voltage drop in 208/120 volt bus duct: 5.435 or 2.61%
 Maximum loss in 208/120 volt bus duct: 11.826 kw
 Maximum loss in 600 volt bus duct: 6.401 kw
 TOTAL MAXIMUM LOSS 18.227 kw

I.3 Cost of Materials and Installation Labour

(a) ALUMINUM WIRES IN CONDUIT

	Length Feet	<u>Cost of Materials</u>		<u>Installation Labour</u>	
		Rate per 1,000 Ft.	Amount	Rate per 1,000 Ft.	Manhours
6 wires 500 MCM in 2-3" conduits	300	\$12,989.00	\$3,896.00	718	215.40
3 wires #4 AWG in 1 1/4" EMT	260	694.00	180.44	114	29.64
4 wires 250 MCM in 2 1/2" conduit	260	4,576.00	1,189.76	335	87.10
4 wires -ditto-	250	4,576.00	1,144.00	335	83.75
4 wires -ditto-	240	4,576.00	1,098.24	335	80.40
4 wires -ditto-	230	4,576.00	1,052.00	335	77.05
3 wires #4 AWG in 1 1/4" EMT	220	694.00	152.68	114	25.08
4 wires 250 MCM in 2 1/2" conduit	220	4,576.00	1,006.72	335	73.70
4 wires -ditto-	210	4,576.00	960.96	335	70.35
4 wires -ditto-	200	4,576.00	915.20	335	67.00
4 wires -ditto-	190	4,576.00	869.44	335	63.65
3 wires #4 AWG in 1 1/4" EMT	180	694.00	124.92	114	20.52
4 wires 250 MCM in 2 1/2" conduit	180	4,576.00	823.68	335	60.30
4 wires -ditto-	170	4,576.00	777.92	335	56.95
4 wires -ditto-	160	4,576.00	732.16	335	53.60
4 wires -ditto-	150	4,576.00	686.40	335	50.25
3 wires #4 AWG in 1 1/4" EMT	140	694.00	97.16	114	15.96
4 wires 250 MCM in 2 1/2" conduit	140	4,576.00	640.64	335	46.90
4 wires -ditto-	130	4,576.00	594.88	335	43.55
4 wires -ditto-	120	4,576.00	549.12	335	40.20
3 wires #1 AWG in 1 1/2" EMT	100	1,148.50	114.85	124	12.40
			<u>\$17,508.15</u>		<u>1,273.75</u>
Main Distribution Panelboard (details on page: 31)		14,462.77	14,462.77		186.00
Total cost of materials			\$31,970.92		1,459.75
Installation labour 1,459.75 @ \$5.75			8,393.56		manhours
GRAND TOTAL			<u>\$40,364.48</u>		

I.3 Cost of Materials and Installation Labour (Continued)

(b) CORRUGATED ALUMINIUM SHEATHED CABLES

	Length Feet	<u>Cost of Materials</u>		<u>Installation Labour</u>	
		Rate per 1,000 Ft.	Amount	Rate per 1,000 Ft.	Manhours
3 cables 750 MCM 3 conductor #4 AWG cable	300	\$7,776.00	\$2,332.80	285	85.50
4 cables 4/0 AWG	260	698.00	181.48	40	10.40
4 cables 4/0 AWG	260	3,872.00	1,006.72	180	46.80
4 cables 4/0 AWG	250	3,872.00	968.00	180	45.00
4 cables 4/0 AWG	240	3,872.00	929.28	180	43.20
4 cables 4/0 AWG	230	3,872.00	890.56	180	41.40
3 conductor #4 AWG cable	220	698.00	153.56	40	8.80
4 cables 4/0 AWG	220	3,872.00	851.54	180	39.60
4 cables 4/0 AWG	210	3,872.00	813.12	180	37.80
4 cables 4/0 AWG	200	3,872.00	774.40	180	36.00
4 cables 4/0 AWG	190	3,872.00	735.68	180	34.20
3 conductor #4 AWG cable	180	698.00	125.64	40	7.20
4 cables 4/0 AWG	180	3,872.00	696.96	180	32.40
4 cables 4/0 AWG	170	3,872.00	658.24	180	30.60
4 cables 4/0 AWG	160	3,872.00	619.52	180	28.80
4 cables 4/0 AWG	150	3,872.00	580.80	180	27.00
3 conductor #4 AWG cable	140	698.00	97.72	40	5.60
4 cables 4/0 AWG	140	3,872.00	542.08	180	25.20
4 cables 4/0 AWG	130	3,872.00	503.36	180	23.40
4 cables 4/0 AWG	120	3,872.00	464.64	180	21.60
3 conductor #1 AWG cable	100	1,124.00	<u>112.40</u>	42	<u>4.20</u>
			\$14,038.80		634.70
Main Distribution					
Panelboard including					
750 kva, 600-208/120					
volt transformer					
(details on page: 31)					
		14,462.77	<u>14,462.77</u>	186	<u>186.00</u>
Total Cost of Materials			\$28,501.57		820.70
Installation Labour	820.70	5.75	<u>4,719.03</u>		
GRAND TOTAL			<u>\$33,220.60</u>		

I.3 Cost of Materials and Installation Labour (Continued)(c) BUS DUCTS

	Quantity	Cost of Materials		Installation Labour	
		Rate	Amount	Rate	Manhours
3 pole, 600 volt 600 amp. feeder type bus duct	40'	\$ 10.50	\$ 420.00	0.45	18.00
3 pole, 600 volt 800 amp. plug-in type bus duct	260'	15.50	4,030.00	0.50	130.00
Reducer from 800 ampere bus duct	1	86.00	86.00	4.50	4.50
60 amp. 3 wire plug(C.B.)	4	99.00	396.00	1.95	7.80
100 amp. 3 wire plug(C.B.)	1	99.00	99.00	3.00	3.00
600 amp. 3 wire plug(C.B.)	1	761.00	761.00	8.00	8.00
4 pole, full neutral 600 amp. plug-in type bus duct	40'	17.00	680.00	0.60	24.00
4 pole, full neutral 2500 amp. plug-in type bus duct	220'	60.50	13,310.00	1.10	242.00
Reducer from 2500 ampere bus duct	1	274.00	274.00	12.00	12.00
200 amp. 4 wire plug(C.B.)	15	232.00	3,480.00	4.70	70.50
Transformer connection	1	255.00	255.00	6.00	6.00
1500 amp. 600 volt 4 pole breaker	1	2,492.00	2,492.00	40.00	40.00
800 amp. 600 volt 4 pole breaker	1	758.21	758.21	15.00	15.00
750 kva, 600-208/120 volt transformer	1	6,624.00	<u>6,624.00</u>	135.00	<u>135.00</u>
Total Cost of Materials			\$33,666.51		715.80
Installation Labour	715.80	5.75	<u>4,115.85</u>		
GRAND TOTAL			<u>\$37,782.36</u>		

Appendix II

SCHEME B(600 volt system)II.1 Unit Rates

The following units rates were obtained for the cost study:

TYPE R90 ALUMINIUM WIRES

	Cost of Materials	Installation Labour
	Rate per 1,000 feet	
500 MCM	\$1,301.00	58 Manhours
2/0 AWG	339.00	32
#1 AWG	260.00	23

CONDUITS FOR THE ABOVE WIRES

	Rate per 100 feet	
3" Rigid Conduit	\$ 259.15	18.5 Manhours
2" EMT	46.60	6.5
1½" EMT	36.85	5.5

TYPE R90 ALUMINIUM SHEATHED CABLES
WITH ALUMINIUM CONDUCTOR/S

	Rate per 1,000 feet	
750 MCM	\$2,592.00	85 Manhours
4 conductors 2/0	2,522.00	52
4 conductors #1 AWG	1,408.00	45
3 conductors #1 AWG	1,124.00	42

Scheme B (Continued)MAIN DISTRIBUTION PANELBOARD

consisting of:

1 - 1500 ampere, 600 volt, 3 phase, 4 wire breaker	\$2,492.00
1 - 600 ampere, 600 volt, 3 phase, 3 wire breaker	608.85
4 - 150 ampere, 600 volt, 3 phase, 4 wire breakers	761.82
10 - 90 ampere, 600 volt, 3 phase, 3 wire breaker	80.92
1 - Factory assembled panel for 600 volt distribution	<u>440.00</u>
Total cost of materials	<u>\$5,192.75</u>
Installation labour	<u>121 Manhours</u>

BUS DUCTS WITH ALUMINIUM BUS BARS
AND THEIR ACCESSORIES RATED AT 347/600 VOLTS

		Rate per foot	
600 ampere 3 pole, feeder type	\$ 10.50	0.45 Manhour	
1600 ampere 4 pole, half neutral plug-in type	36.00	0.85	
Reducer from 1600 amperes bus duct	each 145.00	6.00	
150 ampere 4 pole bus plug (C.B.)	each 232.00	3.70	
100 ampere 3 pole bus plug (C.B.)	each 99.00	3.00	
90 ampere 4 pole bus plug (C.B.)	each 106.50	2.80	
15 kva, 600-208/120 volt dry type transformer	each 458.85	4.00	

II.2 Voltage Drop and Loss Calculations

(a) ALUMINIUM WIRES IN CONDUIT

	Feeder Capacity Amperes	Line to Line Voltage Drop volts	Maximum Loss kw
Roof feeder	600	5.274	3.164
15th floor	135	7.722	1.043
14th floor	75	6.844	0.513
13th floor	75	6.570	0.493
12th floor	75	6.296	0.473
11th floor	135	6.534	0.882
10th floor	75	5.749	0.431
9th floor	75	5.475	0.411
8th floor	75	5.201	0.390
7th floor	135	5.346	0.722
6th floor	75	4.654	0.349
5th floor	75	4.380	0.329
4th floor	75	4.106	0.308
3rd floor	135	4.158	0.561
2nd floor	75	3.559	0.267
1st floor	75	3.285	0.246
Basement	100	3.650	<u>0.365</u>
Total maximum loss			<u>10.967</u>

Maximum voltage drop occurs in 15th floor feeder.

$$\text{Maximum percent drop: } \frac{7.722}{600} \times 100 = \underline{1.287 \text{ percent}}$$

II.2 Voltage Drop and Loss Calculations (Continued)

(b) CORRUGATED ALUMINIUM SHEATHED CABLES

	Feeder Capacity Amperes	Line to Line Voltage Drop volts	Maximum Loss kw
Roof feeder	600	9.720	5.732
15th floor	135	7.722	1.043
14th floor	75	6.844	0.513
13th floor	75	6.570	0.493
12th floor	75	6.296	0.473
11th floor	135	6.534	0.882
10th floor	75	5.749	0.431
9th floor	75	5.475	0.411
8th floor	75	5.201	0.390
7th floor	135	5.346	0.722
6th floor	75	4.654	0.349
5th floor	75	4.380	0.329
4th floor	75	4.106	0.308
3rd floor	135	4.158	0.561
2nd floor	75	3.559	0.267
1st floor	75	3.285	0.246
Basement	100	3.650	<u>0.365</u>
Total maximum loss			<u>13.535</u>

Maximum voltage drop occurs in the roof feeder.

$$\text{Maximum percent drop: } \frac{9.72}{600} \times 100 = \underline{1.62\%}$$

II.2 Voltage Drop and Loss Calculations (Continued)

(c) BUS DUCT

Length of Section feet	Estimated Maximum Section Current amperes	Line to Line Voltage Drop volts	Maximum Loss kw
100	1,600	2.600	4.160
20	1,523	0.500	0.762
10	1,465	0.240	0.352
10	1,407	0.230	0.324
10	1,302	0.210	0.273
10	1,244	0.200	0.249
10	1,186	0.190	0.225
10	1,128	0.180	0.203
10	1,023	0.170	0.174
10	965	0.160	0.154
10	907	0.150	0.136
10	849	0.140	0.119
10	744	0.125	0.093
10	686	0.110	0.075
10	628	0.090	0.057
10	570	0.080	0.046
40	465	1.080	0.502

Total voltage drop: 6.455 or 1.08%

Total maximum loss: 7.905 kw

II.3 Cost of Materials and Installation Labour

(a) ALUMINIUM WIRES IN CONDUIT

	Length feet	<u>Cost of Materials</u>		<u>Installation Labour</u>	
		Rate per 1,000 feet	Amount	Rate per 1,000 feet	Manhours
6 wires 500 MCM in 2-3" conduits	300	\$12,989.00	\$3,896.70	718	215.40
4 wires 2/0 AWG in 2" EMT	260	1,822.00	473.72	193	50.18
4 wires #1 AWG in 1½" EMT	250	1,418.00	354.63	147	36.75
4 wires -ditto-	240	1,418.00	340.44	147	35.28
4 wires -ditto-	230	1,418.00	326.25	147	33.81
4 wires 2/0 AWG in 2" EMT	220	1,822.00	400.84	193	42.41
4 wires #1 AWG in 1½" EMT	210	1,418.00	297.88	147	30.87
4 wires -ditto-	200	1,418.00	283.70	147	29.40
4 wires -ditto-	190	1,418.00	269.52	147	27.93
4 wires 2/0 AWG in 2" EMT	180	1,822.00	327.96	193	34.74
4 wires #1 AWG in 1½" EMT	170	1,418.00	241.15	147	24.99
4 wires -ditto-	160	1,418.00	226.96	147	23.52
4 wires -ditto-	150	1,418.00	212.78	147	22.05
4 wires 2/0 AWG in 2" EMT	140	1,822.00	255.08	193	27.02
4 wires #1 AWG in 1½" EMT	130	1,418.00	184.41	147	19.11
4 wires -ditto-	120	1,418.00	170.22	147	17.64
3 wires -ditto-	100	1,148.50	114.85	124	12.40
15 kva, 600-208/120 volt dry type transformers	15	458.85	6,882.75	4	60.00
Main Distribution Panelboard (details on page: 39)	1	5,192.75	5,192.75	121	121.00
Difference in cost of ballast for 347 volts in place of 120 volts @ 45¢ for 480 lamps per floor i.e. \$216.00	15	216.00	3,240.00		
Total cost of materials			\$23,692.59		867.55
Installation labour	867.55	5.75	4,988.41		
GRAND TOTAL			<u>\$28,681.00</u>		

II.3 Cost of Materials and Installation Labour (Continued)

(b) CORRUGATED ALUMINIUM SHEATHED CABLES

	Length feet	Cost of Materials		Installation Labour	
		Rate per 1,000 feet	Amount	Rate per 1,000 feet	Manhours
3 cables 750 MCM	300	\$7,776.00	\$2,332.80	285	85.50
4 conductor 2/0 AWG cable	260	2,522.00	655.72	52	13.52
4 conductor #1 AWG cable	250	1,408.00	352.00	45	11.25
4 conductor #1 AWG "	240	1,408.00	337.92	45	10.80
4 conductor #1 AWG "	230	1,408.00	323.84	45	10.35
4 conductor 2/0 AWG "	220	2,522.00	554.84	52	11.44
4 conductor #1 AWG cable	210	1,408.00	295.68	45	9.45
4 conductor #1 AWG "	200	1,408.00	281.60	45	9.00
4 conductor #1 AWG "	190	1,408.00	267.52	45	8.55
4 conductor 2/0 AWG "	180	2,522.00	453.96	52	9.36
4 conductor #1 AWG "	170	1,408.00	239.36	45	7.65
4 conductor #1 AWG "	160	1,408.00	225.28	45	7.20
4 conductor #1 AWG "	150	1,408.00	211.20	45	6.75
4 conductor 2/0 AWG "	140	2,522.00	353.08	52	7.28
4 conductor #1 AWG "	130	1,408.00	183.04	45	5.85
4 conductor #1 AWG "	120	1,408.00	168.96	45	5.40
3 conductor #1 AWG "	100	1,124.00	112.40	42	4.20
15 kva, 600-208/120 volt dry type transformers	15	458.85	6,882.75	4	60.00
Main Distribution Panelboard (details on page: 39)	1	5,192.75	5,192.75	121	121.00
Difference in cost of ballast for 347 volts in place of 120 volts @ 45¢ for 480 lamps per floor i.e. \$216.00	15	216.00	3,240.00		
Total Cost of Materials			\$22,664.70		
Installation Labour	404.55	5.75	2,326.16		404.55
GRAND TOTAL			<u>\$24,990.86</u>		

II.3 Cost of Materials and Installation Labour (Continued)

(c) BUS DUCTS

	Quantity	Cost of Materials		Installation Labour	
		Rate	Amount	Rate	Manhours
3 pole, 600 volt 600 amp. feeder type bus duct	40'	\$ 10.50	\$ 420.00	0.45	18.00
4 pole, 347/600 volt half neutral 1600 amp. plug-in type bus duct	260'	36.00	9,360.00	0.85	221.00
Reducer from 1600 ampere bus duct	1	145.00	145.00	6.00	6.00
90 amp. 4 wire plug (C.B.)	11	106.50	1,171.50	2.80	30.80
150 amp. 4 wire plug(C.B.)	4	232.00	928.00	3.70	14.80
100 amp. 3 wire plug(C.B.)	1	99.00	99.00	3.00	3.00
Transformer connection	1	171.00	171.00	5.00	5.00
15 kva, 600-208/120 volt dry type transformers	15	458.85	6,882.75	4.00	60.00
Difference in cost of ballast for 347 volts in place of 120 volts @ 45¢ for 480 lamps per floor i.e. \$216.00 per floor	15	216.00	<u>3,240.00</u>		
Total Cost of Materials			\$22,317.25		
Installation Labour	358.60	5.75	<u>2,061.95</u>		358.60
GRAND TOTAL			<u>\$24,379.20</u>		

Appendix III

SCHEME C

(208/120 volt system)

III.1 Unit Rates

The following unit rates were obtained for the cost study:

TYPE R90 ALUMINIUM WIRES

	Cost of Materials	Installation Labour
	Rate per 1,000 feet	
1,000 MCM	\$2,672.00	96 Manhours
750 MCM	2,193.00	80
400 MCM	1,136.00	54
250 MCM	660.00	45

CONDUITS FOR THE ABOVE WIRES

	Rate per 100 feet	
4" Rigid Conduit	427.15	30.0 Manhours
3½" Rigid Conduit	350.40	22.0
3" Rigid Conduit	259.15	18.5
2½" Rigid Conduit	193.60	15.5

TYPE R90 ALUMINIUM SHEATHED CABLES
WITH ALUMINIUM CONDUCTOR/S

	Rate per 1,000 feet	
1,000 MCM	\$3,848.00	90 Manhours
400 MCM	1,711.00	65
4/0 AWG	966.00	45

Scheme C (Continued)MAINS DISTRIBUTION PANELBOARD

consisting of:

1 - 4,000 ampere, 3 phase, 4 wire breaker	\$ 6,680.00
1 - 1,600 ampere, 3 phase, 4 wire breaker	2,010.40
5 - 600 ampere, 3 phase, 4 wire breakers	5,600.00
11 - 200 ampere, 3 phase, 4 wire breakers	11,272.80
1 Factory assembled bar riser	<u>543.20</u>
Total cost of materials	<u>\$26,107.20</u>
Installation labour	<u>159 Manhours</u>

BUS DUCTS WITH ALUMINIUM BUS BARS
AND THEIR ACCESSORIES

		Rate per foot	
1600 ampere 3 pole feeder type		\$ 28.00	0.65 Manhour
4000 ampere 4 pole half neutral plug-in type		88.00	1.20
Reducer from 4000 ampere bus duct	each	429.00	10.00
400 ampere 4 wire plug (C.B.)	each	495.00	11.00
300 ampere 4 wire plug (C.B.)	each	495.00	11.00
200 ampere 4 wire plug (C.B.)	each	240.00	4.70

III.2 Voltage Drop and Loss Calculations

(a) ALUMINIUM WIRES IN CONDUIT

	Feeder Capacity Amperes	Line to Line Voltage Drop volts	Maximum Loss kw
Roof feeder	1500	4.388	6.581
15th floor	400	4.061	1.626
14th floor	200	5.850	1.170
13th floor	200	5.626	1.123
12th floor	200	5.382	1.076
11th floor	400	3.436	1.375
10th floor	200	4.914	0.983
9th floor	200	4.680	0.936
8th floor	200	4.446	0.889
7th floor	400	2.812	1.125
6th floor	200	3.978	0.796
5th floor	200	3.744	0.749
4th floor	200	3.510	0.702
3rd floor	400	2.187	0.875
2nd floor	200	3.042	0.608
1st floor	200	2.808	0.561
Basement	270	1.976	0.534
Total maximum loss			<u>21.709</u>

Maximum drop occurs in 14th floor feeder.

$$\text{Maximum percent drop: } \frac{5.85}{208} \times 100 = \underline{2.81\%}$$

III.2 Voltage Drop and Loss Calculations (Continued)

(b) CORRUGATED ALUMINIUM SHEATHED CABLES

	Feeder Capacity Amperes	Line to Line Voltage Drop volts	Maximum Loss kw
Roof Feeder	1500	9.225	13.838
15th floor	400	10.400	4.160
14th floor	200	9.360	1.872
13th floor	200	9.000	1.800
12th floor	200	8.280	1.656
11th floor	400	8.800	3.520
10th floor	200	7.560	1.512
9th floor	200	7.200	1.440
8th floor	200	6.840	1.368
7th floor	400	7.200	2.880
6th floor	200	6.120	1.224
5th floor	200	5.760	1.152
4th floor	200	5.400	1.080
3rd floor	400	5.600	2.240
2nd floor	200	4.680	0.936
1st floor	200	4.320	0.864
Basement	270	4.860	<u>1.312</u>
Total maximum loss			<u>42.854</u>

Maximum drop occurs in 15th floor feeder.

$$\text{Maximum percent drop: } \frac{10.40}{208} \times 100 = 5\%$$

III.2 Voltage Drop and Loss Calculations (Continued)

(c) BUS DUCT

Length of Section feet	Estimated Maximum Section Current amperes	Line to Line Voltage Drop volts	Maximum Loss kw
100	4,000	2.350	9.400
20	3,806	0.276	1.050
10	3,662	0.215	0.788
10	3,518	0.210	0.738
10	3,230	0.185	0.598
10	3,086	0.180	0.555
10	2,942	0.175	0.515
10	2,798	0.165	0.461
10	2,510	0.145	0.364
10	2,366	0.135	0.319
10	2,222	0.130	0.289
10	2,078	0.120	0.249
10	1,790	0.115	0.206
10	1,646	0.100	0.165
10	1,502	0.080	0.121
10	1,358	0.075	0.102
40	1,070	0.660	0.707

Total voltage drop: 4.716 or 2.27%

Total maximum loss: 16.627 kw

III.3 Cost of Materials and Installation Labour

(a) ALUMINIUM WIRES IN CONDUIT

	Length feet	Cost of Materials		Installation Labour	
		Rate per 1,000 Ft.	Amount	Rate per 1,000 Ft.	Manhours
9 wires 1000 MCM in 3-4" conduits	300	\$36,862.50	\$11,058.75	1764	592.20
3 wires 750 MCM and 1 wire 250 MCM in 3½" conduit	260	10,743.40	2,793.15	505	131.30
4 wires 250 MCM in 2½" conduit	250	4,476.00	1,119.00	335	83.75
4 wires -ditto-	240	4,476.00	1,074.24	335	80.40
4 wires -ditto-	230	4,476.00	1,029.48	335	77.05
3 wires 750 MCM and 1 wire 250 MCM in 3½" conduit	220	10,743.40	2,363.46	505	111.10
4 wires 250 MCM in 2½" conduit	210	4,476.00	939.96	335	70.35
4 wires -ditto-	200	4,476.00	895.20	335	67.00
4 wires -ditto-	190	4,476.00	850.44	335	63.65
3 wires 750 MCM and 1 wire 250 MCM in 3½" conduit	180	10,743.40	1,933.74	505	90.90
4 wires 250 MCM in 2½" conduit	170	4,476.00	760.92	335	56.95
4 wires -ditto-	160	4,476.00	716.16	335	53.60
4 wires -ditto-	150	4,476.00	671.40	335	50.25
3 wires 750 MCM and 1 wire 250 MCM in 3½" conduit	140	10,743.40	1,504.02	505	70.70
4 wires 250 MCM in 2½" conduit	130	4,476.00	581.88	335	43.55
4 wires -ditto-	120	4,476.00	537.12	335	40.20
3 wires 400 MCM in 3" conduit	100	5,999.00	<u>599.90</u>	347	<u>34.70</u>
			\$29,428.85		1,717.65
Main Distribution Panelboard (details on page: 47)	1	26,107.20	<u>26,107.20</u>	159	<u>159.00</u>
Cost of materials			\$55,536.05		1,876.65
Installation labour	1,876.65	5.75	<u>10,790.74</u>		
GRAND TOTAL			<u>\$66,326.79</u>		

III.3 Cost of Materials and Installation Labour (Continued)

(b) CORRUGATED ALUMINIUM SHEATHED CABLES

	Length feet	Cost of Materials		Installation Labour	
		Rate per 1,000 ft.	Amount	Rate per 1,000 ft.	Manhours
6 cables 1000 MCM	300	\$23,088.00	\$ 6,926.40	540	162.00
3 cables 400 MCM and 1 cable 4/0 AWG	260	6,101.00	1,586.26	240	62.40
4 cables 4/0 AWG	250	3,872.00	968.00	180	45.00
4 cables 4/0 AWG	240	3,872.00	929.28	180	43.20
4 cables 4/0 AWG	230	3,872.00	890.56	180	41.40
3 cables 400 MCM and 1 cable 4/0 AWG	220	6,101.00	1,342.22	240	52.80
4 cables 4/0 AWG	210	3,872.00	813.12	180	37.80
4 cables 4/0 AWG	200	3,872.00	774.40	180	36.00
4 cables 4/0 AWG	190	3,872.00	735.68	180	34.20
3 cables 400 MCM and 1 cable 4/0 AWG	180	6,101.00	1,098.18	240	43.20
4 cables 4/0 AWG	170	3,872.00	658.24	180	30.60
4 cables 4/0 AWG	160	3,872.00	619.52	180	28.80
4 cables 4/0 AWG	150	3,872.00	580.80	180	27.00
3 cables 400 MCM and 1 cable 4/0 AWG	140	6,101.00	854.14	240	33.60
4 cables 4/0 AWG	130	3,872.00	503.36	180	23.40
4 cables 4/0 AWG	120	3,872.00	464.64	180	21.60
3 cables 4/0 AWG	100	2,904.00	290.40	135	13.50
			<u>\$20,035.20</u>		<u>736.50</u>
Main Distribution Panelboard (details on page: 47)	1	26,107.20	<u>26,107.20</u>	159	<u>159.00</u>
Total Cost of Materials			\$46,142.40		895.50
Installation Labour	895.50	5.75	<u>5,149.13</u>		
GRAND TOTAL			<u>\$51,291.53</u>		

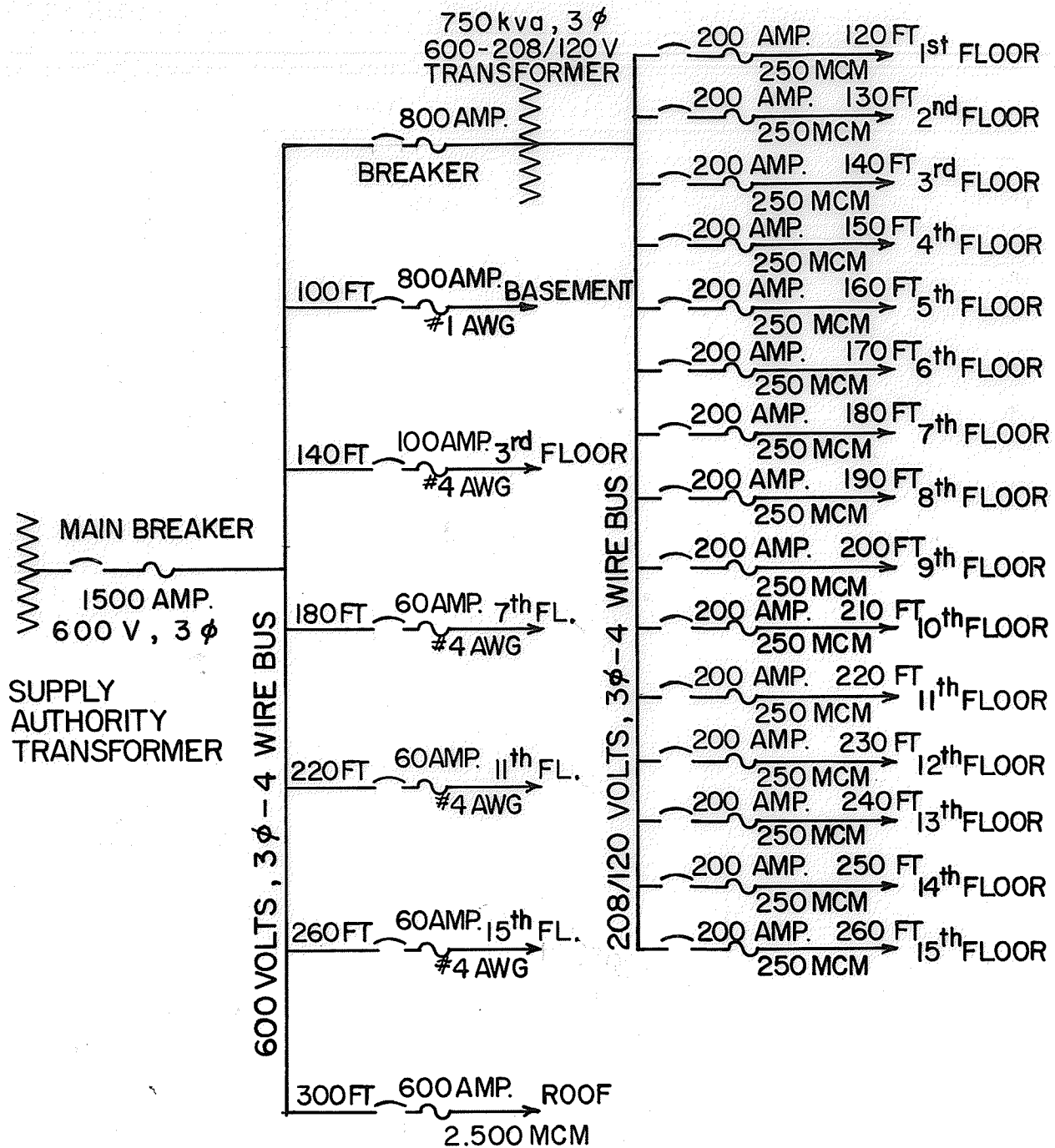
III.3 Cost of Materials and Installation Labour (Continued)

(c) BUS DUCT

	Quantity	Cost of Materials		Installation Labour	
		Rate	Amount	Rate	Manhours
3 pole, 1600 ampere, feeder type bus duct	40'	\$ 28.00	\$ 1,120.00	0.65	26.00
4 pole, 4000 ampere, half neutral plug- in type bus duct	260'	88.00	22,880.00	1.20	312.00
Reducer from 4000 ampere bus duct	1	429.00	429.00	10.00	10.00
400 amp. 4 wire plug(C.B.)	4	495.00	1,980.00	11.00	44.00
300 amp. 4 wire plug(C.B.)	1	495.00	495.00	11.00	11.00
200 amp. 4 wire plug(C.B.)	11	240.00	2,640.00	4.70	51.70
Transformer connection	1	404.00	404.00	7.00	7.00
Total Cost of Materials			\$29,948.00		461.70
Installation Labour	461.70	5.75	<u>2,654.78</u>		
GRAND TOTAL			<u>\$32,602.78</u>		

REFERENCES

1. Canadian Electrical Code, Part I - CSA Standard C22.1 - 1969;
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2. "Westinghouse Quick Selector" 1969-70 Edition, Electrical Equipment -
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3. "Aluminium Sheathed Cables - The Modern Wiring Method" Catalog AS - 67,
Canada Wire and Cable Company Limited, Toronto, Ontario.
4. "Bus Duct - Engineering and Test Data" Application Data, Data H-30-
660, Canadian Westinghouse Company Limited, Hamilton, Ontario.
5. "Canada Wire, Aluminium-Aluminium" Catalog EAAS 70, Canada Wire and
Cable Company Limited, Toronto, Ontario.



FIGURES FOR CURRENT IN AMPERES INDICATE LOAD AND NOT
BREAKER/FUSE CAPACITIES.

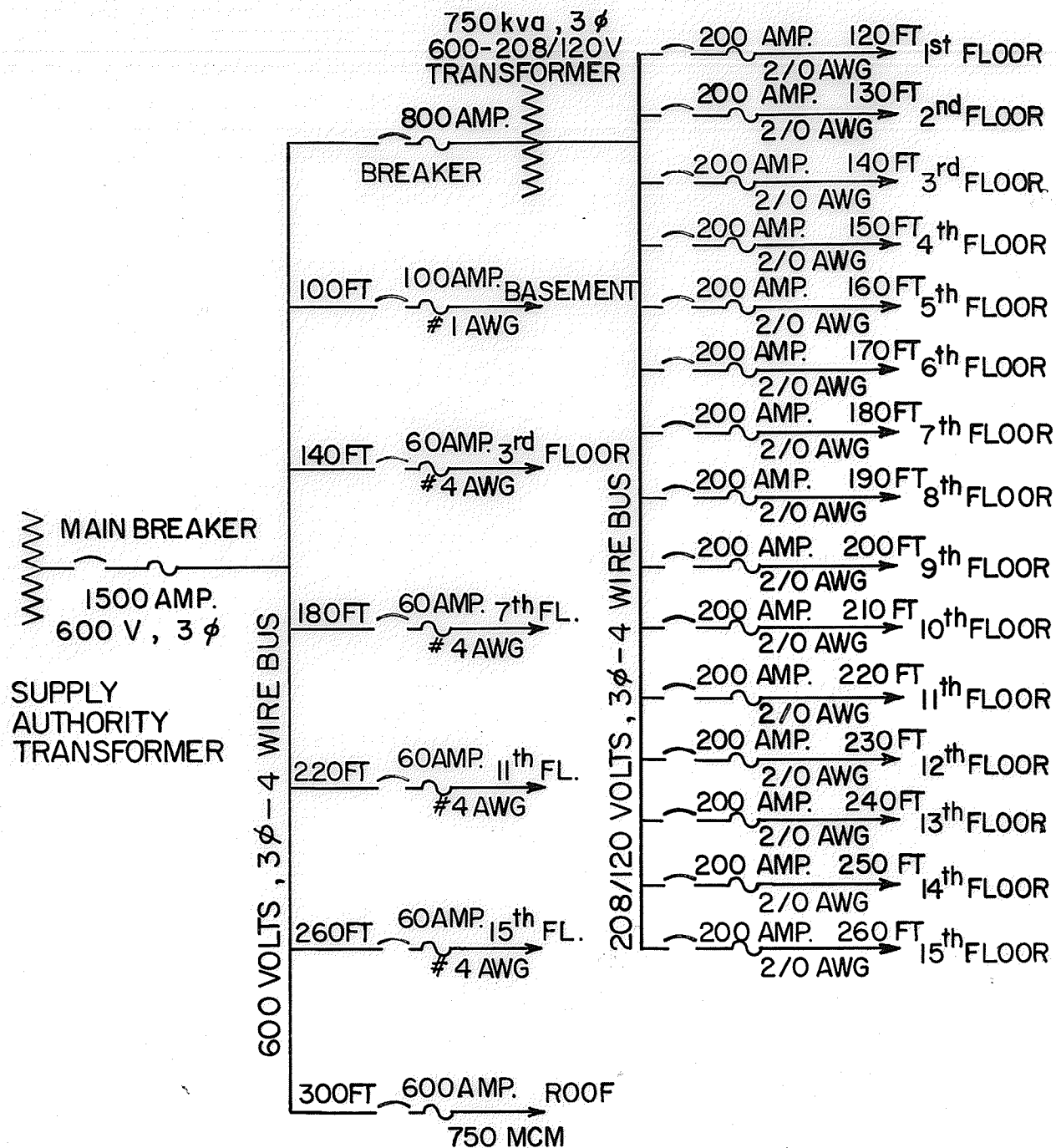
SCHEME A

SINGLE LINE DIAGRAM

NOT TO SCALE

ALUMINUM WIRES IN CONDUIT

DRG. NO. 1



FIGURES FOR CURRENT IN AMPERES INDICATE LOAD AND NOT
BREAKER / FUSE CAPACITIES.

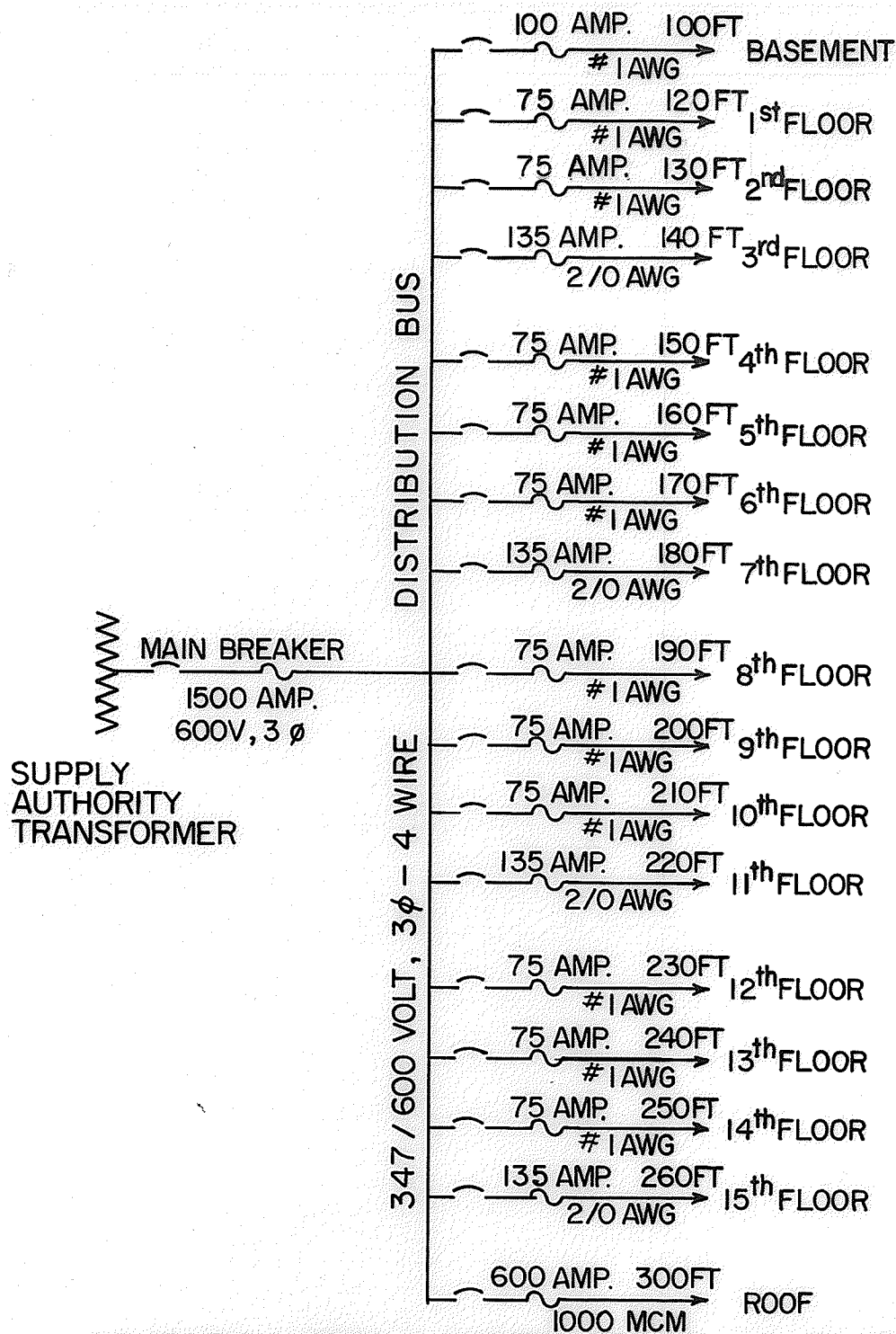
SCHEME A

SINGLE LINE DIAGRAM

CORRUGATED ALUMINUM SHEATHED CABLES

NOT TO SCALE

DRG. NO. 3



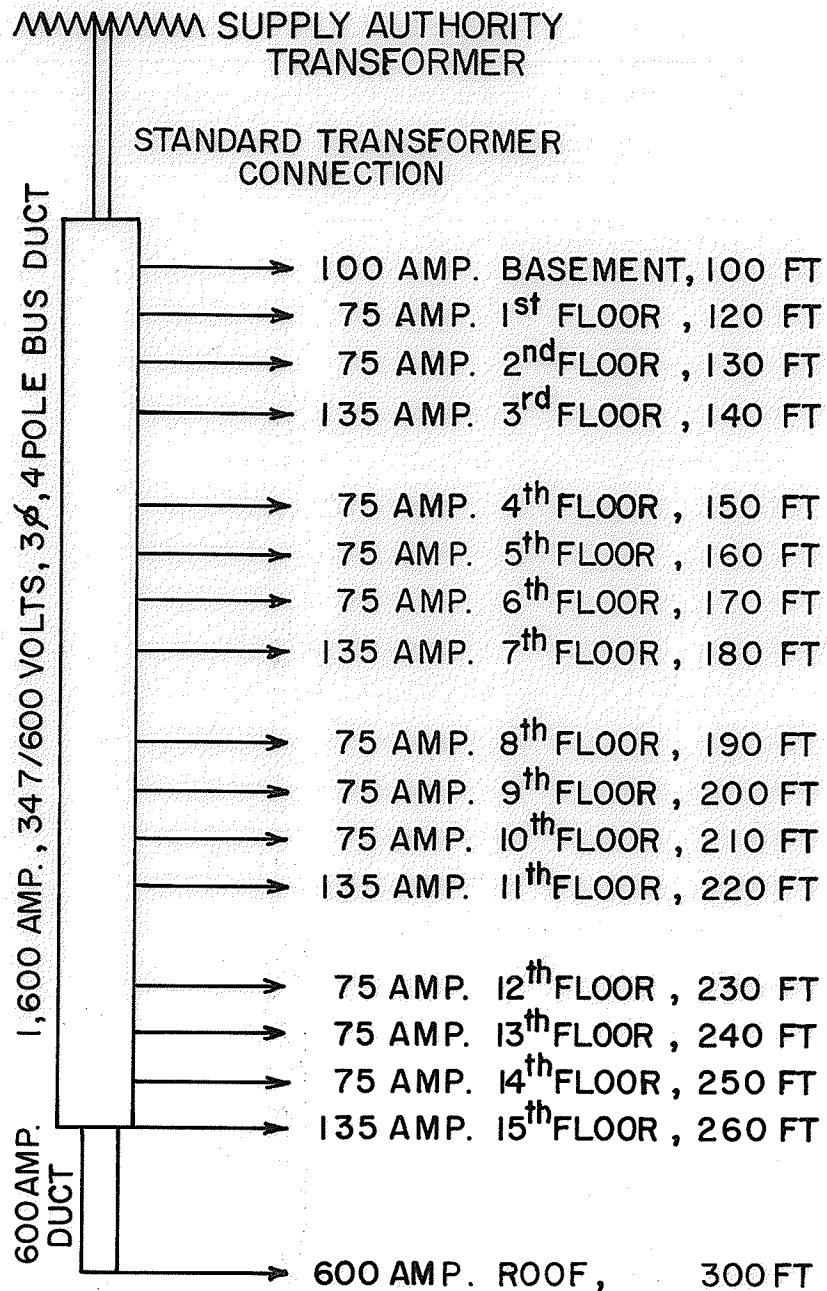
FIGURES FOR CURRENT IN AMPERES INDICATE LOAD AND NOT BREAKER / FUSE CAPACITIES.

SCHEME B

SINGLE LINE DIAGRAM
NOT TO SCALE

ALUMINUM WIRES IN CONDUIT

DRG. NO. 4



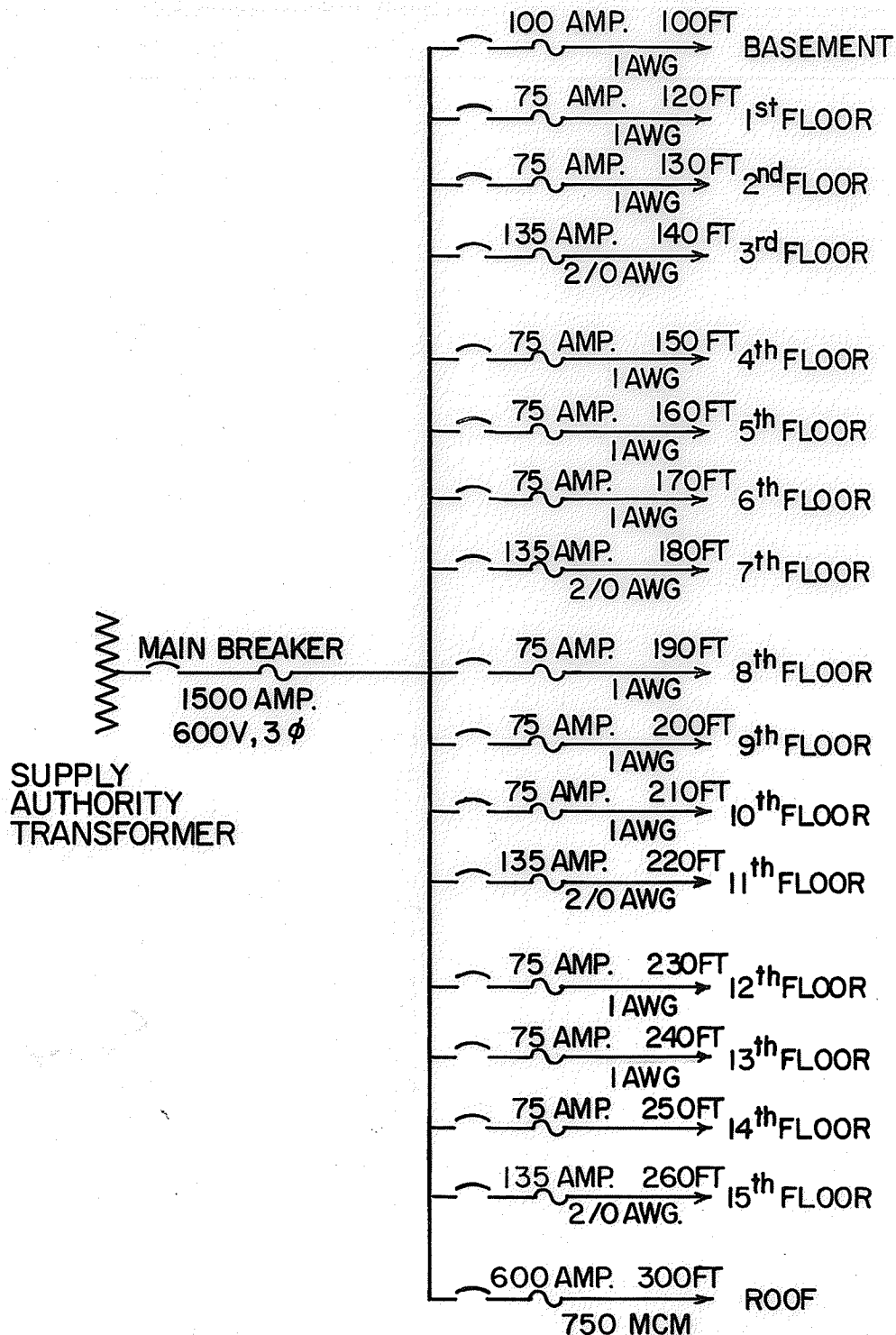
FIGURES FOR CURRENT IN AMPERES INDICATE LOAD AND NOT BREAKER/FUSE CAPACITIES.

SINGLE LINE DIAGRAM
NOT TO SCALE

SCHEME B

BUS DUCT

DRG. NO. 5



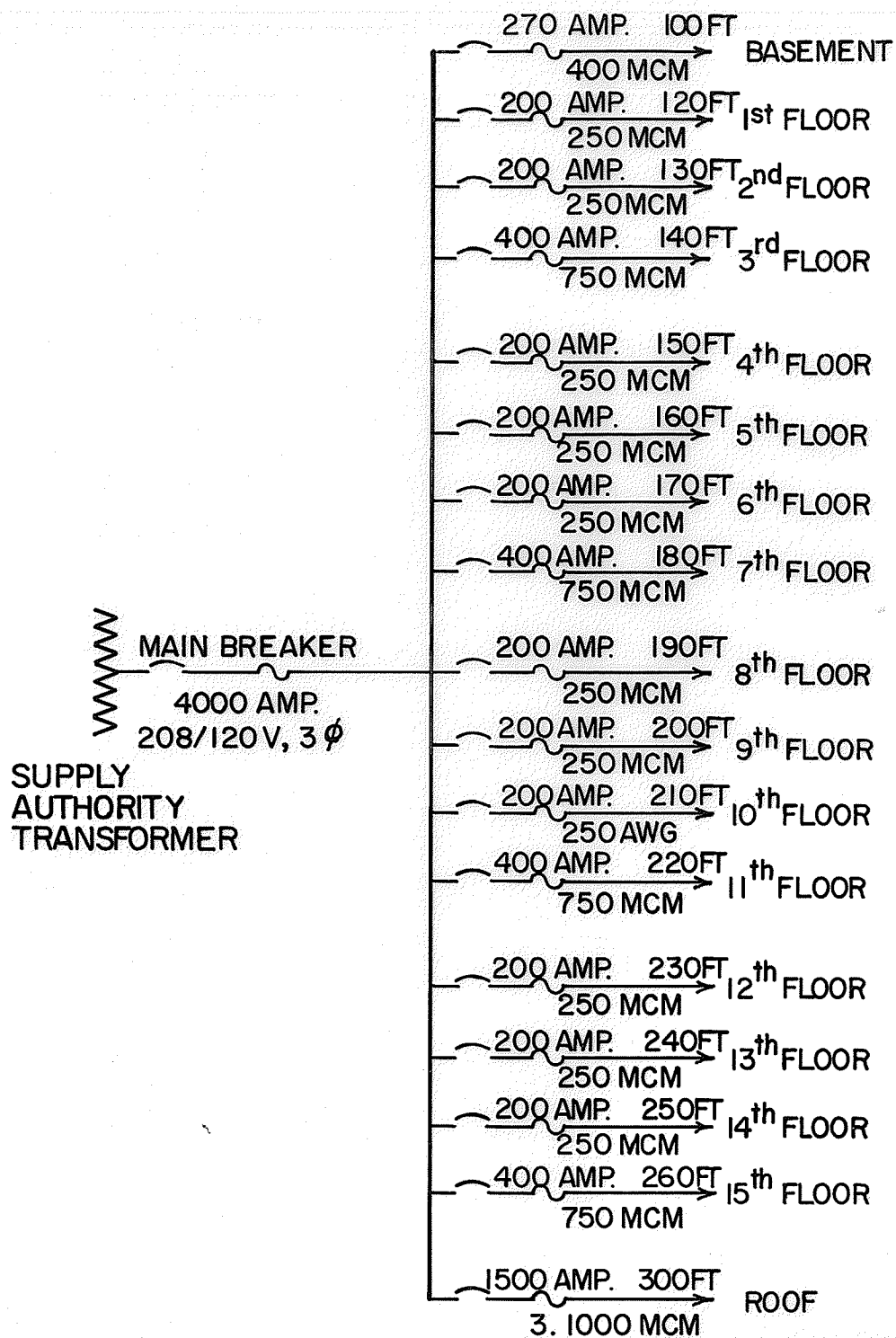
FIGURES FOR CURRENT IN AMPERES INDICATE LOAD AND NOT BREAKER/FUSE CAPACITIES.

SCHEME B

SINGLE LINE DIAGRAM
NOT TO SCALE

CORRUGATED ALUMINUM SHEATHED CABLES

DRG. NO. 6



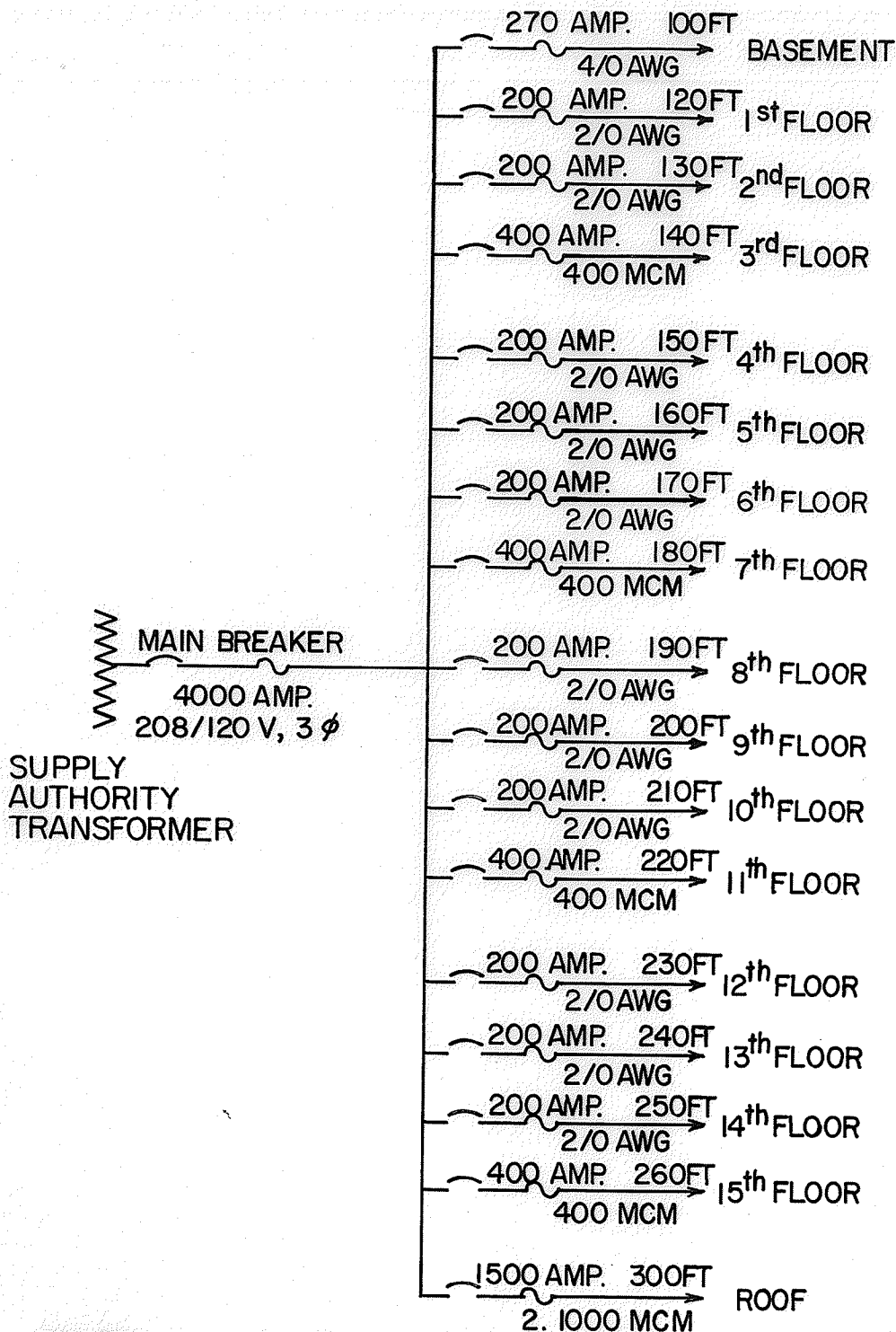
FIGURES FOR CURRENT IN AMPERES INDICATE LOAD AND NOT BREAKER/FUSE CAPACITIES.

SCHEME C

SINGLE LINE DIAGRAM
NOT TO SCALE

ALUMINUM WIRES IN CONDUIT

DRG. NO. 7



FIGURES FOR CURRENT IN AMPERES INDICATE LOAD AND NOT BREAKER/FUSE CAPACITIES.

SCHEME C

SINGLE LINE DIAGRAM
NOT TO SCALE

CORRUGATE ALUMINUM SHEATHED CABLES

DRG. NO. 9