The Design of Server Rooms

Don Gingrich
RMIT University
School of Computer Science and Information Technology

Abstract

This paper looks at several aspects of the infrastructure that is critical for the operation of computer systems. Requirements for achieving acceptable to optimum results in these areas are discussed. The scope of this paper makes it impossible to present complete detail on any topic. Each of the key areas represents a substantial portion of a university level discipline. The range of topics discussed makes in-depth coverage of the topics impossible but references are provided to allow for further detailed investigation, should it be required.

Introduction

While hardware and software configuration is generally considered to be the primary domain of the System Administrator, a strong argument can be made that *all* aspects of the environment for systems should be the complete domain. This paper discusses several of the major considerations related to the design and operation of the machine rooms in which critical systems are housed.

The days of the "glass-house" machine room in which mainframe systems were maintained behind glass walls in strictly controlled conditions have well and truly passed. Yet there remains a requirement for secure locations that can provide controlled climate, clean power, security and ease of connection to external systems. With the current state of the art in computing, it is now common to find many smaller systems doing the work that a single large mainframe would previously . Thus the co-location of these systems also makes many aspects of their administration easier.

Preliminary Considerations and Overview

The design of a machine room and project management of its construction at first seems well outside of the scope of system administration. In an absolute sense it probably is beyond the scope, but this is a case where the old adage, *"If you want something done right, do it yourself."* applies.

In many organisations there is a separate property management group that has general responsibility for buildings, air-conditioning, heating, plumbing, and electrical installations. Unfortunately, these property management groups, in general, rarely have a real understanding of the requirements of computer rooms. The reason for this is that, in several critical areas, computer rooms need to be designed quite a bit differently from the rest of an office building. These areas include air conditioning, quality and security of the power supply, floor loading, and provision for the data communications required to connect the computers to the rest of the organisations assets. The floor loading is particularly important if you are planning for an Uninteruptible Power Supply(UPS) unit and/or safe for storage of backup media.

Since these requirements are non-standard it is necessary, in planning the project, to make significantly greater allowance for delivery times of specialised equipment. It is also necessary to allow for longer construction times by the trades-persons involved in the installation and construction since non-standard construction techniques and a higher standard of quality are often required.

In this paper the stages in the development of a machine room will be considered in the order that they would occur in an actual project.

Planning and Politics

A critical issue in the development of a machine room is convincing senior management of the need to spend significant money on the development. This can be difficult since a machine room is commonly seen as an expense, not as a productive asset. However, as organisations continue to have a greater requirement for an "Internet Presence" it is easier to justify the infrastructure required to keep the required systems operational twenty-four hours per day, seven days a week. An hour of downtime on the Internet is a long time.

The best approach is to look at the economic implications of not having a properly designed machine room and the costs associated with some of these. As an example, not having a suitable UPS can result in data loss and significantly greater down-time. Find ways of estimating the value of the data. A really rough approach that may be good enough is to look at the time spent in collecting and entering the data times the cost of the labour involved. This will result in an estimate which is usually significantly lower than the data's actual value to the business, but still a substantial number, in most cases.

In a software development business there are often invoices that can be used as an indication of data value. Be creative, but logical. Remember that any justification that is developed will probably be checked by accountants at some stage of the process.

Another justification that can work in industry is to point at potential down-time and multiply it by the charge-out rate of the people who depend on systems that will be protected. Twenty people who have a charge-out rate of $100 per hour is $2000 per hour. A few hours of that can quickly justify a fairly substantial UPS, for example. This may not work in the CBD of most cities, though, since the electrical utilities generally have really good uptime in these areas. Of course, when they go down, they stay down for some time since most of the supply network is underground. Based on the experience of the former State Electricity Commission of Victoria, it is reasonable to say that a typical fault in overhead supply is rectified in about four to eight hours while an underground fault can take from one to several days. And it could be worse, does anyone remember the Auckland outage of February, 1998? [12] In any case, it would take more than a simple UPS to deal with a problem of this magnitude.

The planning process for the layout and equipment required should occur in parallel with the justification process. It is a good idea to start by defining the requirements for an ideal configuration. Then look at places where a lower cost alternative might not significantly compromise the basic goals. Look for aspects of the overall plan that can be added later, in next year's budget, for example, as a way of reducing the cost in the present project. Postponing portions of the optimum target environment may be a better option than substituting inferior equipment. Remember to consider the cost of the additional down-time in providing these forward estimates. A demonstration of why the optimum equipment will have a lower total cost of ownership, combined with good forward estimates may result in the total project being funded after all.

Defining the Basic Goals

Try to answer the question, "Why is this machine room being built?" Will the group that uses the machines be static in size and scope of mission or will it be growing? Is the room for a work-group or is it for the entire organisation? Is it intended to use the room as a communications hub as well as machine room? Just what equipment will need to be in the room? Now? Five years from now?

One aspect of machine room design that this paper specifically does *not* address is the design of machine rooms for co-location of equipment or rooms that are shared by groups either from different companies or possibly even from different divisions within the same corporate entity. Security in these environments is sufficiently complex to necessitate an additional paper to adequately discuss these requirements. Some passing references may be relevant to the issues in shared environments, but no attempt is made to thoroughly describe these complexities.

The assumption is often made that since computer equipment is continually becoming more powerful, the size and power requirements for the room will reduce in the future, provided the projects or people that it supports remain more or less constant. This is an unwise assumption since new releases of most software packages and operating systems seem to require increased computing resources. Worse, this often occurs at a rate somewhat greater than the increase in available hardware capacity.

What does seem to be happening is that the density of computing power as defined by mega-flops per cubic metre is increasing. This has implications for several of the critical systems such as power supplies, air conditioning, and communications that need to be designed into the room.

Space is another key issue. If the room is to be located in a high-rise building where every square meter is billed at a substantial cost then keeping the room to a bare minimum size will need to be a goal. But if space is less expensive then it may be better to start with a room that is obviously too large for requirements. It is a common experience to find more and more equipment appearing once the room has been built. More space will also mean better airflow around equipment for cooling and easier access to equipment racks to add, modify, or repair the equipment without the necessity of removing the equipment from the racks. One option is to design the initial machine room with the minimum space required, but with an adjoining room which could be an office or even storage space. If this room is separated from the machine room by an easily removable partition then a route to future expansion is provided. It may be necessary to consider the security implications of an "easily removable" partition depending on the sensitivity of the data on the systems.

Early in the design process consideration will need to be given to the preferred routing for power and communications cabling, as well as how the air-conditioning will be supplied. In many cases the preferred solution is a raised floor. This is not an inexpensive option. But it can result in a very neat appearance in a machine room. If there is a requirement to bring customers or potential customers into the room to be impressed, then this is likely the best option.

If the only requirement is a functional system then it may be possible to put cable trays either on the wall or the ceiling. This may be a better option in smaller rooms or in cases where the room may be temporary. It may not be worthwhile to invest in permanent fittings.

Even with a raised floor, a reasonable argument can be made in favour of wall or ceiling mounted communications cabling. There may be significant advantage in separating power and communications cables to reduce problems of electrical noise. Preliminary reports from those who have used the new gigabit copper network equipment suggest that gigabit cables will be particularly sensitive to noise. Also the routes of communications cables change more frequently than the routes of power cables. If the cables are visible there is more incentive to keep them neat. This avoids the "Gordian knot" of cables that often develops under a raised floor.

There is potentially significant lead time in sourcing the type of air conditioning that is needed for a computer room, depending on the time of the year. Sizing the equipment may be a difficult exercise. The simplest solution may be to add up the wattage rating of all of the equipment in the room and assume that all of the power input eventually appears as heat. This is not quite as silly as it sounds. Some of the power is being used to move air with the fans in units, and some is being used to spin hard disk drives, but a substantial proportion of that power is eventually seen as heat due to the friction in the bearings. The power supplied to the electronics is almost all eventually dissipated as heat. In general, about 80-90% of the power input into most computing equipment eventually heats the room. If in doubt go with the higher numbers. Having too much air conditioning is less likely to be a problem than is too little. Make allowance for the likely higher density of future equipment and the higher heat load that this will represent.

The quantity of electricity used, commonly referred to as the electrical load will also be critical in calculating the size of the UPS that will supply the room. The assumption here is that if the systems are important enough for a dedicated room, then they probably need quality electricity supply. Remember that most UPSs have a percentage of power that is lost between the input and the equipment that is supplied. This loss is also seen as heat. It will be a percentage of the load that is supplied. Thus if the UPS is only half loaded it will effectively only produce 1/2 of the rated heat loss.

Once these preliminary decisions have been made it becomes easier to consider their relative merits of the various specific equipment that may be installed.

Power Supply Considerations

Some sort of UPS or power conditioning is generally considered to be an essential requirement for a machine room. The quality of power available from most electricity supply authorities or companies is surprisingly bad. This is not completely the fault of the supplier, the cost of filtering to clean up the supply would rapidly become uneconomic given that a substantial portion of the electrical equipment in use is not as sensitive as computer equipment.

But the assumption is that if you are building a server room to house your equipment, then it is important to, and possibly critical to the operation of the business. If this is the case then a UPS is essential.

People working in the electrical field have their own jargon. In discussing power quality some understanding of this jargon is necessary. In any electrical system there is a **circuit** in which the electrical energy moves from a source to a destination and generally does some useful work on the way. Of course. if there is a fault in the installation, the energy may do some damage on the way. The standard analogy used in most electrical texts equates the invisible flow of electricity with a flow of water through a pipe. In this analogy the pressure in the pipe is equivalent to the **voltage**, the diameter of the pipe is the analogue of the **resistance**, and the volume of water flowing through the pipe represents the **current**. Voltage is normally expressed in **Volts**, current in **Amperes** or **Amps**, and resistance in **Ohms**.

Electricity as it is commonly used is alternating current or AC. In AC the voltage varies between positive and negative in a sine wave pattern. Australian electricity completes 50 sine waves fluctuations per second. In an ideal world the sine wave for the current is exactly synchronised with the sine wave for the voltage. In this case they are said to be "in phase". Being in phase means that the power supplied to the equipment is equal to the Volts multiplied by the Amperes. But this is seldom the case with real electrical circuits. Typically the current and voltage are out of sync or, to use a bit more jargon, out of phase. The degree to which they are out of phase is expressed as the "power Factor". Why is this an issue? because in this case the actual power supplied to the equipment or **load** is the Volts multiplied by the Amperes multiplied by the power Factor. In typical electrical installations the power factor is between 0.8 and 0.95. UPS units are rated in KVA. A KVA is Volts times Amperes divided by one thousand. (e.g. 4 A at 250 V = 1 KVA) One KVA is equal to one KW (Kilowatt or 1 thousand Watts) when the power factor is 1.0, but as the power factor becomes smaller it takes more KVA to equal a KW. The problem is that computer equipment is rated in Watts or KW and the UPS are rated in KVA. Older PC power supplies had really poor power factors on the order of 0.8 thus many UPS manufacturers who quote a KW output will quote around 0.8 times the KVA value. For reference, a typical house will use between 2 and 10 KVA, depending on the amount of heating, air conditioning and other high power appliances are in use. A large PC will use around 0.5 KVA, depending on the number of hard drives installed.

There are a variety of methods for improving the quality of the electricity supply for a machine room. There are differences between the basic design philosophies of the equipment. It is necessary to consider the requirements since different designs have different strengths and weaknesses.

The bare minimum approach is to install a line conditioning system. This will have electrical filters that remove some of the electrical noise that is present on most power systems. An example of this is the line "spikes" generated when arc welders are in operation. Since these spikes can be as high as several thousand volts the potential for damage should be obvious. A properly designed line conditioner will remove these spikes.

A line conditioner can also deal with limited problems where the line voltage drops below the rated values over short periods of time. An example of this is the way the lights may dim in a home when a large air-conditioner or electric heater start. If this condition persists for more than a second or two then it will be beyond the capacity of a line conditioner. Clearly the minimal approach or using a line conditioner is not what is required in most cases, but it may be sufficient protection for a non-critical printer and it would represent a substantial savings as compared to more sophisticated methods.

The available types of UPS in common use are, standby, line interactive, and full on-line. They are listed in order of their relative cost. The standby UPS has a low power battery charging system, combined with some filtering and conditioning and an inverter system that will supply the full rated output of the unit. See figure 1. This type system senses the failure of the mains and, with the assistance of the filters will get switched to the battery power with only a minor glitch in the power supply. Most of the

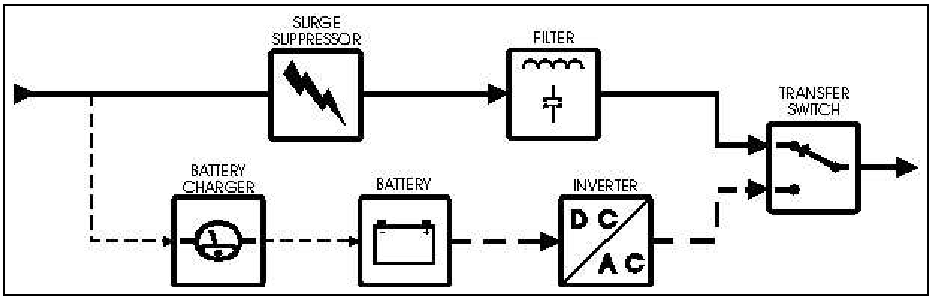


Figure 1: Block schematic of a standby UPS. Image ©American Power Conversion Corp.[4]

disturbance is removed by the filters that are commonly a part of this type of UPS. This should be within the tolerance of the computer power supply. But since there generally is a glitch, this type of unit is not recommended for high reliability systems.

The second type, line interactive, uses what amounts to a sophisticated variation on the standby system. See figure 2 In the normal operating mode this type of UPS has an active filter system that is also connected to the battery and can draw power from the battery in case of a prolonged voltage sag.

A further variation on the line interactive type of UPS is marketed by American Power Conversion as a delta-conversion UPS. See figure 3. Because the comparison circuitry is continually monitoring the output and effectively using the battery as a source of energy to modify flaws in the output waveform the equipment supplied by this UPS receives good quality power. And, since all of the power supplying the load is not double converted, this type of UPS achieves significantly higher efficiency than the full on-line system The primary disadvantages are that this type of system is limited to the frequency of the supply and the load is not as totally isolated from the supply as in the case of a true online UPS. But the higher efficiency and consequent lower cost of operation may be a sufficient advantage to make this a good choice, particularly if a generator as a long term backup is not a realistic consideration.

The frequency is not normally a major issue, but some power supplies in computers specify a limited frequency range and the manufacturer may void the warranty if the frequency goes out of range. There can be problems with the supply frequency if the UPS is connected through a transfer switch to a generator that cuts in in case of a mains failure to provide longer emergency supply than the batteries.

The interactive system typically does not put as much electrical noise back into the electrical distribution system as an on-line system does.

A full on-line system uses a rectifier that is capable of supplying the full load plus charging current. See figure 4. This connects to the battery bank and through it to a full-load inverter system which supplies the load. This means that the load is always supplied by the inverter system. In the event of a mains failure, there is no change in the way that the load is supplied. There is no possibility of a glitch in this configuration. There is also no way for electrical noise and spikes to get from the input to the output of this type of unit in its normal operating mode. The output frequency is determined by the UPS and not the incoming supply so it will maintain a constant frequency even when connected to a diesel generator system.

The disadvantage of a true online UPS is primarily cost. Since both the rectifier and inverter are continuously supplying the equipment, they need to be designed to work at the required power level. These units generally average around \$1000-1250 Australian per KVA of power output. This type of UPS is not as efficient as the other types since there are losses in both rectification and inversion. These losses also contribute to the heat load in the room ad need to be considered in the air-conditioning calculations.

The full-wave rectifier also imposes some significant harmonics on the incoming supply as well as affecting the power factor. This effect is increased since it is supplying the full output of the UPS. The problems of harmonics and power factor can be corrected by the use of an active filter system on the incoming supply. The filter acts in a way that is similar to the output section of the APC system. It has sensors that measure the current in the supply to the UPS and the voltage waveform. The supply current to the UPS is represented by the waveform diagrammed in the top right corner of figure 5. It

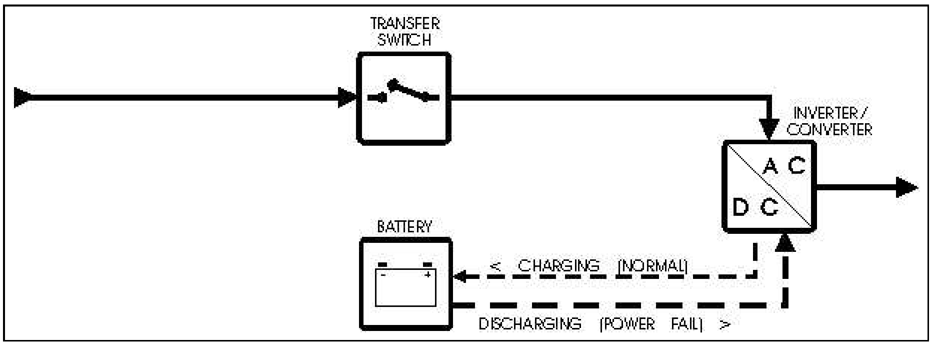


Figure 2: Block schematic of a line-interactive UPS. Image ©American Power Conversion Corp.[5]

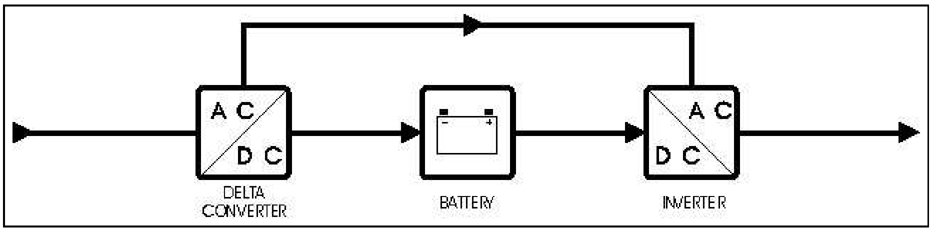


Figure 3: Simplified block schematic of a delta-conversion online UPS. Image ©American Power Conversion Corp.[6]

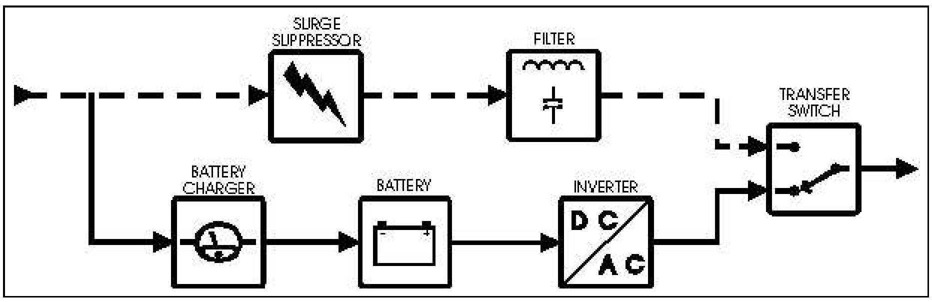


Figure 4: Block schematic of an online ("true") UPS. Image ©American Power Conversion Corp. [6]

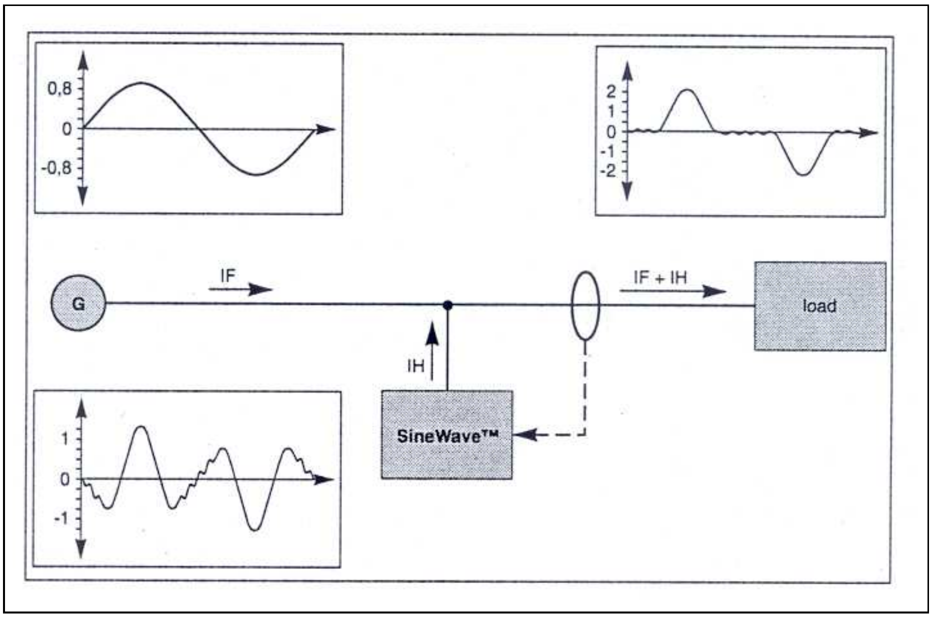


Figure 5: Diagram of an MGE SineWave Active Harmonic Filter with input and output waveforms. ©MGE UPS Systems.[13]

supplies electrical current, as required, to counteract the harmonics that the rectifier circuit generates in the power line. This current waveform is represented by the diagram in the lower left corner of figure 5. And, provided that the load is not too large for the filter to compensate, the resultant waveform that is seen by the rest of the electrical system in the building looks reasonably close to the diagram in the top left of figure 5.[13] The filter is also designed to correct the power factor which assists in reducing the electricity used at the meter. The filter is not cheap, at a cost of about $10,000A for a 40 KVA unit, but it reduces effective metered power usage by a factor of 10-25%.

Another consideration in the selection of a UPS is the question of what happens if the UPS itself fails. If there is a single UPS that supplies the entire room, then if it fails, the entire room is off supply. This may be taken as a potential argument in favour of a number of smaller UPSs, each supplying no more than a single rack of equipment. The flaw in this logic is that either the small UPSs are built to a lower standard than a large UPS or the combination of enough small UPS to supply all of the equipment in the room will have a cost greater than a large unit of equivalent capacity.

Most UPS manufacturers will provide switching systems that provide a degree of redundancy in larger UPS systems. The units installed in the RMIT Computer Science machine room are two 40 KVA units with switching so that either can carry the entire supply, but in normal operating conditions they will supply the room for twice the time. Should it be necessary to supply additional equipment with a total of over 40 KVA the solution will be to add another 40 KVA unit. In this configuration, any two of the UPS units will supply enough power for the room.

For a smaller machine room that requires less than 16 KVA total, one of the better solutions is the APC Symetra. It is designed with "hot plugable" battery and converter units. The converters each supply 4 KVA of load and there is room for 5 converters so that there is a degree of redundancy. Additional battery cabinets are available to increase the time that the unit can supply power.

One other consideration that is obvious but often overlooked is the lighting in the machine room. If access to the room for the shutdown of some or all of the equipment is required in a power outage, then some provision for lighting needs to be made. In most cases it is not difficult to add a lighting circuit to the mains panel supplied by the UPS. Then there will be available lighting as long as the UPS is working. It might be a good idea to ask for at least one or two fittings with the built in emergency batteries so that employees can exit the room safely after the UPS has shutdown.

It may seem that a suitably sized UPS solves all of the power supply problems. But this is not the case, remember the example of Auckland. Or even a case where an overhead or underground high voltage distribution cable is damaged. It could take from four to eight hours to replace a pole for an overhead system and from a day or two to a month for underground distribution. So why bother with an UPS? Electrical distribution systems are divided into smaller sections that are typically between several hundred metres and a kilometre or two at most in urban areas. There is a complex system of switches interconnecting the various "feeders". In most cases, provided that the low voltage substation supplying a customer's premises is not in the immediately affected section, the utility will open and close switches in the high voltage as necessary to get as many of the affected customers as possible back on line in around one to two hours in normal conditions. Response times may vary with privatised electricity distribution companies replacing the government owned systems. With a bit of local research it may be possible to find values for the probability of outage and the average and maximum times that have been reported. If your systems absolutely *must* be up then this research is worthwhile as a basis for determining requirements.

A short digression is necessary here to describe the basics of how the electrical distribution system is designed. The generators produce electricity at a voltage around five to ten thousand Volts. To reduce losses this Voltage is increased to between 220KV and 500KV for transmission from the generation station to the urban area where the consumers are located. At the outskirts of the urban area the voltage is reduced to typically 66KV and these cables go to "Zone Substations". Zone substations reduce the voltage to between 6.6 and 22KV. The cables from these, referred to as feeders supply the transformers that convert the Voltage to 240/415 to supply consumer equipment. There are sound technical reasons for this complexity, but they are not relevant to this discussion.

What is important is that large consumers, RMIT for example, frequently have electricity supplied from dedicated low voltage substations on their premises. These are often supplied from more than one feeder. So it is possible to buy a device called an automatic transfer switch to improve the security of electrical supply to the machine room. For some fairly complex reasons it is dangerous to permanently connect the supply from low voltage transformers connected to two different feeders. An automatic transfer switch solves this problem. The UPS is connected via the switch to the normal supply substation which is referred to as the primary supply. As long as that substation is working nothing happens. But, if the primary supply shuts down for whatever reason, the switch automatically disconnects from the primary and connects to the secondary supply. This happens in less than a second. A UPS will deal with this transfer time easily. There is a problem that may need consideration, though. A fractional second loss of power may shut down the Air Conditioning. Air conditioning, at the very least, needs to be connected to the transfer switch, but the control circuits may require modification so that the air conditioning system will restart after the transfer switch has operated.

The other option, which is even more expensive, is to install a diesel generator as the other side of the transfer switch. This complicates the design since it will take several seconds for the generator to come up to speed and be ready to supply power. The air conditioning will definitely need a re-start. Also the frequency of the power supplied can vary by several Hertz (or cycles per second). Some UPS units will have difficulty in supplying 50 Hz power if there is too much variation in the generated power.

Clearly each of these options is more expensive than the previous. It is more expensive to have a transfer switch to allow a supply from a different feeder than to simply rely on the utility to restore power before the UPS battery depletes. It is even more expensive to install and maintain a motor-generator set. But each of these options incrementally adds to the security of the power supply. To determine if it really is worth the money it is necessary to carefully analyse the cost of downtime.

There are several more issues with generators. The fuel is flammable, there was a problem with this in the World Trade Center with emergency generators in some of the higher parts of the buildings. The generators are noisy. They need to run for a few minutes every few weeks to months, depending on the recommendations of the manufacturer. One generator at RMIT sounds like a string of large firecrackers every time it is run for testing purposes. But the big advantage is that the technical group is in complete control of the secondary supply. The potential big disadvantage is that technical group is *responsible* for the secondary supply. The procedures for inspection, testing and maintenance of a generator system mean that there will be significant long term costs. And, if the recommended testing, inspection and maintenance procedures are not followed, having a generator will simply provide a false sense of security.

Raised Floor Systems

Raised floors with removable tiles are a common system in use in computer rooms. In most cases there will be between 20 and 30cm space between the *real* floor and the top of the raised floor. In general, more space is better. However it is important to consider the slope of the ramp between the computer room floor and the floor in the rest of the building. The ideal option in the case of new construction would be to have the fixed floor under the computer room set at a lower level than the rest of the floors. Alternatively, if the computer room is to support a large number of workstations with high computing requirements, it might be an option to install raised floors throughout the area. But if a ramp will be required and will be permanently in the server room, remember that it will use about 1M for each 10cm of floor height. Ramps of some sort are a really good idea, if not a necessity, since there is often large and/or heavy equipment that will need to be moved into or out of the room.

Typically raised floors cost between $125. and $275. per square metre. There is a wide variation in the quality of the available options. At the cheap end are floors that use high density particle board for the floor and concrete blocks with PVC alignment caps for the support. These tend to be significantly less stable than systems that use steel supports and bolted steel stringers under moulded steel floor tiles. There are significant differences in the floor loadings associated with these systems. At the low end the allowed loading on a 25mm square is 3kN (kilo-Newton - approximately 300 kilogrammes). With the highest quality this loading doubles. And it is possible to have additional supports installed under the floor and the stringers to increase the working load. As an example the UPS battery cabinets at RMIT computer science have a base of 50mm wide square steel tubing with cross tubing across the base, just to be sure. The cabinets have a mass of 1.3 Tonnes and the base design would, in theory, allow it to have a mass of up to 180 Tonnes as far as the raised floor is concerned. Realistically this cannot be correct since there are certainly some assumptions being made by the floor manufacturer with respect to the percentage of the area of a tile that will actually be supporting a load of this nature. However, it also makes it clear that the engineer who asked for modifications to the battery cabinet design radically over-engineered the job, since a total of 4 corner pads, each 25mmx25mm would support 1.8 Tonnes according to the floor specification.

This an area where engineering assistance is a good idea, though. If the engineer signs off on the job and something happens later it is a far better situation from a liability standpoint, at least. In high rise buildings, particularly, the precise construction technique that was used for the building needs to be considered since the design floor loading for the "real" floor under the raised floor will vary dramatically depending on where it is on the floor plan. Putting a large UPS battery cabinet in the wrong place could have catastrophic consequences.

As you are designing the floor give some consideration to where your equipment will be located. In most cases the machines will be on racks that 10A or larger plugs and flexible cords that supply power points mounted on the rack into which the equipment plugs. The communications cabling will also need to be in the under-floor space in most cases. An ideal underfloor layout will allow for reasonable separation between these two systems. In the case of copper communications cable, if it is necessary for communications to cross the power cables the crossing should be at a right angle to reduce the possibility of electrical induction, which can seriously reduce the data transfer rate due to noise. Induction and noise are not an issue for optical fibre, but it is best if the fibre is situated so that it is not likely to be disturbed often since bending an optical cable too often or too sharply may damage it. Check the specifications of the optical cables that you are using.

In most cases the floor supplier can precut the panels for cable access. This is a really good idea because specialised tools that the installer will have readily available will make the job a *lot* easier for them. And, in the case of MDF core floor tiles, there are occupational health and safety issues involved in cutting the material. It is safer to let someone who is properly equipped do the work.

Unless there is some other requirement, e.g. under floor air-conditioning, it is a good idea to make the holes as large as practicable. If the holes are cut by the supplier then the edges can be supplied smooth or with protective moulding to keep cables from being damaged on the edges.

One of the conventional designs, when cost is effectively no object, is to combine raised flooring with air conditioning that puts positive pressure cool air under the floor and racks that have closed sides, fronts and backs and which are supplied with extractor fans on the top to help the air circulation. If this system is used than any shelves in the racks should also be ventilated. A lower cost option is to use open racks and make sure there is plenty of airflow around the outside.

Air-Conditioning

Air-conditioning is as critical to the safety of equipment as is a secure clean power supply. There are several aspects of machine room air conditioning requirements that make them different from conventional office environments.

- Machine rooms typically run at a lower temperature. A temperature of 20°C is normal in a machine room. At this temperature the electronics in the machines will have operating temperatures around 35-40°C.
- Machine room air conditioning runs 24 hours per day/ 7days per week. This one seems obvious, but many air-conditioning systems are designed with the expectation that they will have 8 or more hours of daily down-time.
- Machine room air conditioning will be cooling no matter what the outside temperature. Conventional air-conditioning is not designed to be cooling at such low external temperatures. Specialised adaptation may be required.
- Because the air-conditioners are continuously cooling and because a machine room is not a high traffic area there is often a problem with humidity. Not high humidity, but low humidity is the common problem.

There are two types of air-conditioning that are commonly used in large buildings, conventional, refrigerant based systems, and chilled water systems in which a chiller is located on the roof and cold water is pumped through a heat exchanger where the cooling is required.

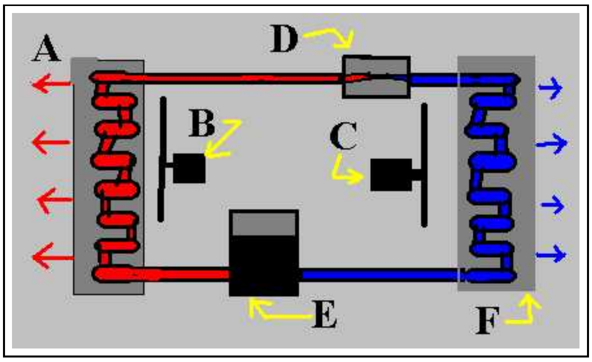
The design of a refrigerant system is diagrammed below.

Refrigerant systems have lower initial cost than chilled water systems. There may also be problems with using the chiller systems for computer room cooling in an office environment since the chillers may be shut down over evenings and weekends. And most chilled water systems also have water condenser cooling towers on the roof. These can be a potential breeding ground for Legionella bacteria if they are not properly maintained. The basic assumption is that this type of refrigeration is generally installed and maintained by the property services group. Thus the actual maintenance issues will hopefully not be an issue for the designer of the machine room.

If a 24x7 source of chilled water is available and a suitable drainage system can be installed to deal with possible leaks, a chilled water system is likely to be the most effective system. Also investigate whether there is redundancy in the chiller equipment before deciding on this option. Combining a chiller based primary system with a refrigerant based backup system may also be an option.

The primary advantage of chilled water is that it can more easily be used to bring the room to a lower working temperature than refrigerant systems. There are several reasons for this. The chilled water is circulated at a temperature of around 4°C. At this temperature it is impossible for the heat exchanger to freeze, no matter what the environmental conditions are in the room. Trying to achieve a working temperature of 20°C using a refrigerant based system, if the relative humidity of the room is below 35-40%, there is a likelihood that the heat exchanger coils will freeze.

If this occurs, the unit will be out of service until it thaws. Worse, there is a possibility that the unit will leak moisture or blow droplets of water over nearby equipment. This can be mitigated to some extent by installing drip trays under the units, particularly if they are ceiling mounted. Due to design problems with the air-conditioning installed during the machine room modifications in November of 2001 at RMIT, the above problems have been observed. Equipment damage was prevented by a combination of drip trays and the use of plastic over the tops of



A - Hot air to Outside
B - Fan to help improve heat transfer from coils to outside.
C - Fan for more efficient transfer of cool air to inside.
D - Expansion Valve
E - Compressor
F - Cool Air to Inside

Figure 6: Diagram of Refrigerant Type Air-Conditioner

racks. It is possible to get refrigerant based units that are equipped with electrical heaters that are designed to de-ice the coils. These are activated either periodically or when the coil temperature goes below 0°C. If this is the case there is less likely to be a freezing problem.

It is probably a good idea to have several small units with at least one extra to provide a degree of redundancy. It is also possible to set up a unified control system that will alternate the system that has the primary role. This has the advantage of allowing at least one unit to alternately be in standby mode. This regular down-time will increase the life of the units and reduce the chances of problems with units freezing.

An option that may be worth considering, particularly in the case of a large chilled water unit, is to put the heat exchanger in an auxiliary room that is designed to prevent water leaking into the main machine room. The cool air can then be ducted into the machine room and, with proper ducting design, directly to the areas of greatest heat load. A properly designed system of this type should provide relatively even temperatures throughout the room.

Humidification may be required as a part of the overall air-conditioning system. By the time air has passed over the heat exchangers a few times the humidity will be getting low. This is not a good thing for several reasons. The primary concern is that low humidity means that static buildup is enhanced. A secondary concern is that low humidity significantly increases the problem of heat exchangers freezing. This is somewhat counterintuitive, but the problem relates to the energy involved in the state-transition between liquid and gas for the water vapour present in the air in the room. If there is not enough water vapour present then the heat exchanger is unable to absorb sufficient heat from the air and the temperature of the heat exchanger drops below 0°C.

Since it is a relatively common occurrence to remove the covers and peripherals from machines a low static environment reduces the chances of electrostatic discharge damage to the equipment. Static reduction, combined with improved effectiveness of the air-conditioning, may be a sufficient argument for controlled humidification of the room. A controlled relative humidity of 50% will solve both problems and be well within the typical requirements of computer equipment. The correct choice of floor will also promote static discharge through the feet rather than through the equipment.

The other issue with low humidity is that low humidity enhances the chances of air-conditioner heat exchanger icing. The reason for this is that dry air releases less heat into the the heat exchanger so that the refrigerant remains at a lower temperature. The vapour which condenses into liquid on the fins releases a lot of energy. But without enough moisture, the small amount of vapour has a greater chance of also making the second transformation to become ice.

Monitors are available to sense when the water has begun to leak from a chilled water system, when a refrigerated system has frozen and begun to spray droplets of water into the room or when the humidity is outside the recommended range. These can be connected to multi channel logging systems or to various security systems. Cost may be an issue in some of these options.

Security

There are two issues in machine room design that relate more or less directly to physical security. They are access control and backup media storage. Access control is critical since, in most cases, physical access to a machine means that an attacker effectively has control of the root or other equivalent administrator account on the system. Control of backup media is important since the backup can be restored on a "cracker" controlled machine to either allow direct access to data, or through access to the password and shadow files, the opportunity to crack the root or other account password at leisure.

There are several methods that are commonly used to control access to the actual machine room. The simplest is bye means of a keyed lock. The disadvantage of this method is that inevitably, over time more keys get cut, keys get lost, and there is no audit trail of persons accessing the room. The advantage is that it is cheap, and that it is a method with which most persons are familiar.

A somewhat better method is a programmable touch-pad system. This has the advantage of no keys to lose and, if the keypad is reprogrammed on a regular basis, a reasonable degree of control over the list of persons having access. Unfortunately, the combinations are often not changed as often as they should be and to make matters worse the "key" is intangible so "sharing" it effectively makes another copy. There is again no audit trail to track who has accessed the room.

The best option is some type of "swipe" or proximity card reader. These systems use a computer database as the back-end and access can be controlled on a very fine-grained basis. For example, it is possible to restrict access to normal working hours for some people while allowing 24x7 access for key administrators.

One potential disadvantage of a centrally administered access control system is that the central people may start to feel that *they* own the access control and grant the access rights. This can be controlled reasonably easily by clearly documenting the authority and responsibility and getting general management sign-off.

In the case of any access control system, regular audits of who has access rights is essential. As an example, does the CEO, who may have limited knowledge of technical computing issues and system administration, *really* require 24x7 access? Does the head of school or department actually *require* out of hours access? What would they do with it if they had access? While it might be a career limiting move to revoke the access of a lot of senior people without any formal discussion, it would be much more likely to work if a position paper clearly limiting access those with a specific requirement for access. After senior management sign off on the policy it should be much easier to explain to them why they do not absolutely require access and that the system administrators would be available to provide "tours" as required for whatever reason. Also consider whether you trust the cleaners to be in the room when there are no administrators also present.

Access for contractors is also an issue, whether they are the tradespeople working on an upgrade to the machine room, contract cleaners, or contract IT staff, they may need to be treated differently than permanent employees. The assumption is often made that contractors or outsource employees may not be as loyal to the organisation. This may not be valid, but possible conflicts of interest in outsourcing definitely need to be considered. And there is no doubt that disgruntled employees are potentially the greatest security risk.

Cleaners and tradespeople probably need to be escorted during the time they are working in the machine room. There are several classic stories in the Risks archives[9] about cleaners either unplugging equipment or disturbing power supplies with the electrical noise from vacuum cleaners or polishers. And most cleaning significantly increases the dust content of the air. It only takes one particle in the wrong place and hard disk can be destroyed. Decide what precautions that you want the tradesmen to take to reduce the risks created by their work and discuss it with them.

The backup tapes that are regularly made are potentially a major security hole. As previously mentioned, with the combination of a backup tape and a suitable system, an attacker can potentially own all of the data that was on the system at the time. Passwords cannot be considered secure if an attacker has a sufficiently fast system and time to launch a brute-force attack. A shadow file is not much use if a tape gets loose.

How should the tapes be protected? At least as carefully as the machines. If there is a requirement for day to day restoration from tapes then at least some of the tapes will need to be stored in close proximity to the machine room. Safes are available that are designed for tape storage. These are rated at around three hours fire resistance at a temperature that is around the likely temperature from a typical office fire. The safes are also designed to withstand a drop of up to 3 metres without damage to their contents.

The ideal solution would involve duplicating the tapes so that one set could immediately be moved to off-site storage while the others were kept available. Make sure that the off-site storage location is secure and staffed by trustworthy employees.

Fire Suppression

As a minimum a machine room needs to have several easily accessible carbon dioxide (CO_2) fire extinguishers and a master "panic shutdown" switch. There should also be sensors in any enclosed space to detect heat or smoke, as well as in the main room.

Unfortunately there is no fire extinguishing system that will meet all of the ideal criteria.

- Minimal or no environmental damage
- Safe for humans
- Safe for machines
- Puts the fire out rapidly

Halon was safe for machines and put the fire out rapidly, but it was bad for the ozone layer and dangerous for anyone who was in the room when the system went off. In most cases the Halon systems have been removed.

New alternatives are being developed. As a start there are a few systems that simply are not an option. Sprinklers are an obvious bad choice. If the room was not designed as a computer room from first principles, there may be sprinklers installed. In combination with installing a more suitable system it would be a good idea to get the sprinklers capped.

A bulk CO_2 system is one possible alternative. CO_2 is heavy and tends to force out the oxygen in the air. This effectively smothers the fire. Since humans also require oxygen it will smother them also. Since CO_2 is heavy and goes to the floor there is a particular safety hazard since the recommended way to exit a fire area is to keep low to avoid the heat of the fire and noxious vapours produced by combustion. Bus since CO_2 is a normal part of the atmosphere there are limited environmental concerns. The volume involved in a machine room is not significant as far as greenhouse gas emissions are concerned.

There is one problem that does need to be addressed with CO_2. When it is released from a high pressure storage tank the reduction in pressure can result in significant cooling. In some circumstances this can cause thermal shock that could damage computing equipment. This effect is clearly visible in CO_2 hand-held fire extinguishers.

A new product that is being sold as a replacement for Halon is Inergen from Ansul. (Note that both Ansul and Inergen are registered trademarks.) It is effectively a mix of nitrogen, argon and CO_2 with the respective percentages being 52, 40 and 8, respectively. [7] This has an action similar to CO_2, with all inert gasses it effectively smothers the fire, but it is not supposed to have the same thermal problems. The CO_2 content is designed to stimulate the breathing reflex and allow workers to breath, not comfortably, but safely as they clear the area. A properly designed system should reduce the oxygen content to 12.5% which will suppress fire in most combustible material. [2]

Fire suppression is not presently installed at RMIT. It is being considered for next year's budget.

Other Considerations

Now that the primary considerations of power, air-conditioning and a floor have been addressed, it becomes necessary to look at the other aspects. It is important to remember that, no matter how permanent the present set of equipment looks, it *will* change, probably sooner than expected.

This probability of change is one of the primary reasons for avoiding proprietary equipment racks. There is no argument that a rack full of equipment or a row of racks full of equipment, all from the same manufacturer, in the manufacturer's branded racks looks impressive. But if history is any guide, there is a reasonable probability that two or three models from now the new equipment will not fit the old racks.

For this reason, it may be a better idea to purchase well-made "generic" racks. It may be possible to retrofit them with different mounts at a lower cost than complete replacement, or in the worst case, equipment can be placed on ventilated shelves. Also with third party racks there is a better chance of being able to mix equipment from different manufacturers in the same rack. Besides, what happens when the sole-supplier agreement with Brand X becomes an agreement with Brand Y and Y's equipment does not fit all of those lovely racks?

Most racks are supplied with a series of power points on one side of the rack. The flexible cord which is supplied with the rack can optionally have whatever power plug is required. A good option is to use captive plugs and under-floor power-points into which they will lock. An option that may be worth considering is to install 30-50mm square slotted conduit up the side of the rack opposite from the power. This provides a neat route for the communications cables and keeps them well away from the power.

The vendor argument in favour of their racks is that they provide features that generic racks do not. These features may include power sequencing, monitoring of the power supply, the potential for independent power feeds, etc. Most of these features can also be arranged with third party racks. It is worth considering dual power supply systems for machines that are equipped with redundant power supplies. It does not make much sense to plug them both into the same power-point under the floor. If you are arranging for a dual supply, it may be possible to have three-phase power in the rails of a rack. If this option is used it means that there is a potential of 415 Volts inside the equipment. Check with the supplier to make sure this is not a problem. This is not saying that the power supply needs to run on 415 Volts, just that in some fault conditions the electrical isolation between the power supplies needs to be properly designed.

In an ideal world there would be a single communications riser in which all cables entering or leaving the room are located. But this is the real world and it just doesn't work that way. The best solution is to determine where the majority of cables are and locate the communications hub in that area. Then look at ways to make it easier to bring the other necessary cables into the room from other directions and then to route them to the hub. One option may be to install ducting with easily removable covers around the sides of the room. Transparent covers for the ducting would make it easier to audit the physical integrity of the cables without needing to open the ducts. This might require custom fabrication so costs may be an issue. If a bit more money is spent in the initial outfitting there will be continuing savings in labour costs as the inevitable changes are made afterwards.

Another possible situation is one in which the group owning the server room does not directly *own* any of the data communications facilities. This split in responsibility is likely to result in problems at some stage of the exercise, but since it is usually engraved in stone it may not be worth fighting. But a server room designed under these conditions requires an alternate patch panel located in the room that has at least one or two spare active ports, depending on the level of flexibility required in the machine room.

Make sure that, in addition to spare power capacity from the UPS, there are also a reasonable percentage of free slots in the electrical distribution panel. A larger panel is not significantly more expensive. The additional cost is roughly equivalent to the cost of a few hours of the electricians time. A later requirement for a larger panel will cost significantly more money and nearly the same number of installation hours as well. The more important issue is that down-time will be required for the upgrade. Depending on the design of the mains panel, it is often possible to add circuit breakers without any need for down-time, provided there is existing space for the new breakers in the panel.

Monitoring the conditions in the machine room is another requirement that is often overlooked. If the building has a combination of shared central UPS and backup generation then power monitoring may not be as critical as it would be in the case of an isolated location with only a 45 minute battery UPS.

Any location will need some sort of environmental monitoring to track what is happening with the air-conditioning. It is surprising just how fast the temperature in a machine room rises after the air-conditioning fails. Administrators need to be notified to be ready to implement controlled shutdowns of non-essential systems in an orderly manner rapidly when problems develop.

There are several ways to implement this. On option is to have a sensor that reports to a central monitoring station where humans can respond to alarms on a round-the-clock basis. These people then call the relevant person to deal with the problem. A good way to implement this is to have a special "hot line" phone or pager that is passed to the duty administrator for the week. This means that the security people need only have one, or at most two contact numbers.

There is newly available hardware that can be installed into a PC to transform it into a central monitoring station. This has the advantage of not requiring a live guard in the circuit. This is also a potential disadvantage if the system has silent failure modes. The key point for a monitoring system is that it must notify someone or something before it goes off line for any reason. Otherwise a fault condition could develop with no notification of the relevant administrators.

As much as possible of the monitoring and shutdown process should be automatic. The remainder should be capable of being remotely initiated, if necessary. For obvious reasons this interface needs to be secure, using a minimum of ssh or its equivalent.

Sources of Information

Finding suppliers for all of the required equipment may initially seem like a nearly insurmountable task. But there are several sources of information that should be considered. If you are employed by a large organisation it is likely that someone else has done similar work. It may well be that your organisation already has a preferred electrical contractor, security consultant, or supplier of fire equipment. Even if it turns out that they are not the best source for what is required, they may be a good place to start. Hopefully they will have the integrity to pass you on to a more qualified alternate if your requirements are not something they normally supply.

The web is another good source of information. The fire suppression information all came from a look at the web. Unfortunately the quality of information available on the web is extremely variable, and not all potential suppliers have a web presence yet. The Yellow Pages either in hard copy or on the web are another good source of possible suppliers.

Visit the computer related trade shows, if possible. These can provide an opportunity to see similar products from several different manufacturers all in one afternoon. And finally, when you are getting closer to a shortlist, post to the SAGE mailing list and ask for good and bad comments about potential suppliers. This aspect of information sharing is one of the benefits of SAGE membership, why not use it.

As a courtesy, try to get back to the unsuccessful potential suppliers as soon as possible after a decision is made. In most cases they have helped you get what you want by either being too expensive and making your preferred supplier look good, or by having a product that simply doesn't meet your requirements, thus forcing a decision in favour of the more expensive preferred supplier.

Concluding Points

Remember that all of this process will involve cooperation of a number of other people. Many aspects of the work need to be done in a particular order. Organising all of the work will take a lot longer than expected. The work will take longer than planned. Allow as much time as possible.

If the job is a renovation of an existing machine room you will need to discuss the minimum requirements for keeping systems on line with the relevant contractors. Work with them to plan the critical path.

At the same time, if the systems are to remain online you will need to discuss physical security issues with the contractors. Masonry dust from hammer drilling, for example, is not good for computer systems. If the contractors know about the requirements, they can provide industrial vacuum cleaners to deal with the dust as it is being created. It is probably a good idea to have an administrator who either is on-site as a liaison or at the very least regularly visits to ensure that the requirements are met. Even top quality trades-people have days when they fail to consider all of the necessary issues. This administrator can justify his/her presence to some extent and make the work of the tradespeople easier by organising power, light, and whatever access may be require.

Actually organising the job so that it concludes on time and within budget is project management at a fairly high level. Good luck!

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