i. Transistorized receivers:

j. Transistorized transmitters;

k. Transistorized 60 to 400 cycles per second converters;

l. Transistorized process control systems: and

m. Power system controls.

(b) The less susceptible category includes:

(i) All vacuum tube equipment (does not include equipment with semiconductor or selenium rectifiers):

a. Transmitters:

b. Receivers:

c. Alarm systems;

d. Intercoms:

e. Teletype-telephone; and

f. Power supplies.

(ii) Equipment employing low current switches, relays, meters:

a. Alarms:

b. Life-support systems:

c. Power system control;

d. Panels:

e. Panel indicators:

f. Status boards; and

g. Process controls.

(iii) Hazardous equipment containing:

a. Detonators:

b. Squibs;

c. Pyrotechnical devices;

d. Explosive mixtures: and

e. Rocket fuels.

(iv) Other:

a. Long power cable runs employing dielectric insulation; and

b. Equipment associated with high energy storage capacitors or inductors.

(c) Least susceptible items include:

(i) High-voltage 60 cycles per second equipment:

a. Transformers:

b. Heavy duty relays;

c. Filament circuit breakers:

d. Heaters:

e. Rotary converters;

f. Motors:

g. Lamps; and

h. Air-insulated power cable runs.

(ii) The less susceptible equipment or components would be made more susceptible if they were connected to long exposed cable runs, such as intersite wiring or overhead exposed power or telephone cables. The equipment can be made less vulnerable if it is protected-.

(4) Hardenina Systems to EMP Effects. There are several approaches to hardening systems to the effects of EMP. These are as follows:

(a) Shielding:

(b) Damage resistance;

(c) Decoupling;

(d) Operational; and

(e) Good practice.

(i) The most common protective technique is to enclose the equipment or complete EOC in a continuous envelope of highly conducting and permeable metallic material. This is often termed "electromagnetic" shielding to differentiate it from other types of shielding, such as a thick layer of concrete, which may be used to reduce the effects of nuclear radiation. In the case of either a large EOC where the entire EOC is enclosed within this metallic sheet or of a small cabinet housing electrical components, special consideration must also be given to the cables which enter and leave the shielded enclosures.

(ii) Special consideration must also be given to providing access into the shielded areas, as well as to ventilation. To prevent the entry of the EMP voltages and currents collected by cables entering or leaving shielded enclosures, special types of filters and surge arrestors may be required. The cables within the structure must also follow certain grounding plans. Special precautions are also required for doors to provide radio frequency interference (RFI) gasketing which, in effect, recreates the effect of *a* continuous metallic sheet when the door is closed, but also permits occasional opening when access is required. In the case of ventilation, special types of screens or waveguides which prevent penetration of electro- magnetic energy, must be employed wherever ventilation ports or holes are used. *Another* approach to reduce the level of EMP in induced transients on cabling systems is by metal oxide varistors (MOV's). Fast acting surge arrestors such as zener diodes may also be employed. The combination;.-however, must be very carefully designed, since the zener diodes are far more sensitive to burn-out themselves than are the metal oxide varistors. Thus, very careful design is required which must be backed by adequate EMP-type test procedures, by a qualified electrical/electronic engineer.

(iii) In addition to increasing the resistance of individual components, the energy applied to these components may be reduced by decreasing the length of the antennas or by-completely decoupling the energy collectors. For example, the antenna or power line cord to a potentially susceptible electronic system can be disconnected during EMP threat periods and reconnected only during the time of actual use or need. Such a technique is relatively simple to accomplish and can be done during the preattack period. The system then could be recoupled and reconnected to the antenna and power line and could then be used for the intended functions during the postattack period.

(iv) Additional details about EMP protection is defined in CPG 2-17 Electromagnetic Pulse Protection Guidance.

f. Chemical and Thermal Environment. Ventilation, heating, and cooling are essential to maintaining a habitable environment in the EOC.

(1) Ventilation, Heating, and Cooling Requirements. The ventilation system must supply not less than 15 cubic feet per minute (cfm) of fresh air per person to the occupied space, of which at least 5 cfm must be outside air. This will be sufficient to supply the necessary oxygen for breathing and to purge the air of carbon dioxide produced by breathing. In most cases, however, it will not be sufficient

to maintain the temperature and humidity within the desired limits. Some form of heating will usually be necessary during cold weather and some form of cooling will be needed during hot weather.

(2) Control of Air Composition.

(a) Control of the chemical environment implies control of the composition of the air. This means supplying air with a sufficiently high oxygen content and a sufficiently low carbon dioxide content to maintain life. It also involves elimination or control of constituents which could be dangerous to life such as carbon monoxide, hydrocarbon fuel vapors, hydrogen, disease pathogens, or other dangerous substances. It can also involve control of odorous substances which, while not dangerous to life, are obnoxious. The approximate composition of atmospheric air, near ground level, is as follows, in percent by volume:

Nitrogen	78.03%
Oxygen	20.99%
Argon, carbon dioxide, hydrogen, and other gases	0.98%
	100.00%

This composition will vary to some extent depending on the concentrations of carbon dioxide and water vapor. For convenience in calculations dry air (air without water vapor) is often taken to be 79 percent nitrogen and 21 percent oxygen, by volume.

(b) Figure I-l shows the approximate relationship between energy expenditure, oxygen consumption, carbon dioxide production and the rate of breathing for various forms of physical activity. The values in the figure are based on a representative value of the respiratory quotient (RQ) of 0.83. The RQ is the -ratio of carbon dioxide production to oxygen consumption during the breathing process and varies with diet and body chemistry. The value of 0.83 is typical for a healthy person on a normal diet. The recommended tolerance levels for prolonged shelter occupancy, such as an EOC, are not less than 17 percent by volume oxygen concentration and not more than 0.5 percent carbon dioxide concentration.

FIGURE **I-1**

ENERGY EXPENDITURE, OXYGEN CONSUMPTION, CARBON DIOXIDE PRODUCTION AND RATE OF BREATHING IN HUMANS

Physical Activity	Energy Expenditure Btu./hr..	Oxygen Consumption cu; ft./hr.	Carbon Dioxide Production cu. ft./hr.	Rate of Breathing cu.ft./hr.
Prone, at rest	300	0.60	0.50	15
Seated, sedentary	400	0.80	0.67	20
Standing, strolling	600	1.20	1.00	30
Walking, 3 MPH	1000	2.00	1.67	50
Heavy work	1500	3.00	2.50	75

The minimum rates of ventilation will be determined by the tolerance limits of low oxygen concentration and/or excessive carbon dioxide concentration.

(3) Effects of Carbon Monoxide (CO). When considering the effects of the chemical environment, include carbon monoxide even though there is essentially none of this gas in normal air and the amount produced by the body is negligibly small.

(a) Carbon monoxide results from the incomplete combustion of carbon in fuels. In confined EOC spaces the most probable source of CO would be tobacco smoking. Pipe smoking produces five times as much CO as cigarettes, and cigars produce almost 20 times as much. It can also result from fuel-burning devices in the EOC, from the exhaust gases of internal combustion engines or could be drawn into the ventilation intake from smoldering fires outside.

(b) Carbon monoxide is insidious in its action since it is invisible, odorless, tasteless, and nonirritating. The human tolerance to CO is very slight. For industrial purposes the allowable concentration is considered to be 100 parts per million (ppm) which is equivalent to 0.01 percent by volume. This is based on an 8-hour workday, 5 days a week, assuming that a person would be in an atmosphere free of CO during the remainder of the time. For exposure over longer sustained periods, lower limits are used. For submarines, the limit is 50 ppm or 0.005 percent by volume and for space cabins the design level is 10 ppm or 0.001 percent by volume.

(c) There is no really satisfactory method of removing carbon monoxide from the air. It is, therefore, necessary to remove the contaminated air and replace it with fresh air. Fortunately a minimum ventilation rate of 3 cfm per person should be adequate to prevent serious build-up of carbon monoxide generated within the EOC, except that which would be included in exhaust gases from an engine. It is obvious, however, that engine exhaust products should not be permitted to enter the EOC space under any circumstances.

(d) In cases where CO from smoldering fires might be drawn into the ventilation intake, it may become necessary to close down and seal off the ventilation system. Under these conditions it would then become necessary to place strict limitations on the amount of smoking permitted to prevent excessive increases in carbon monoxide.

(4) Fresh Air Ventilation for EOC's. In general, the environmental criteria in an EOC cannot be met with fresh air ventilation alone. Some form of mechanical cooling will be necessary in warm weather and some form of heating in cold weather. However, there will be times when fresh air ventilation would be adequate. The environmental control system for the EOC should be designed to allow variation in the amount of fresh air which is taken in so that the ratio of fresh air to recirculated air can be adjusted to take maximum advantage of favorable outside weather conditions.

g. Ventilation (Heating and Cooling). The environmental support system in an EOC should-be capable of maintaining essential comfort conditions. This is often taken as being a dry-bulb temperature of about 75*0. Fahrenheit and a relative humidity of about 50 percent. This would provide an "Effective Temperature" (ET) of about 70*0. as compared to the 82*o.F ET in a fallout shelter. It may be safely assumed that the ventilation required to meet the thermal environmental criteria will be greater than that required to control the chemical environment. There may be times during cold weather when the necessity for maintaining the chemical composition of the air will require ventilationrates greater than are necessary for thermal control. However, the capacity of the ventilation system which must be installed in any shelter facility, including an EOC, will be determined by the requirements for thermal control during hot weather.

(I) Sources of Heat and Moisture in an EOC. The thermal conditions of temperature and humidity which will develop in an EOC are determined by the heat and moisture balance at any given time.

(a) Possible heat sources that might be present are:

(i) Heat losses of the occupants;

(ii) Heat in the ventilation air:

(iii) Heat from lights:

(iv) Heat from mechanical, electrical and communications equipment;

(v) Heat from chemical reactions in life-support systems (not operating when ventilation system is operating):

(vi) Heat transfer to or from the surrounding earth or air:

(vii) Heat from combustion processes such as open flames: and

(viii) Heat from absorption-type refrigeration equipment.

(b) Sources of moisture might include:

(i) Moisture losses of the occupants:

(ii) Moisture in the ventilation air;

(iii) Moisture from leaks in the structure:

(iv) Evaporation from open containers of water, food or from sanitation systems (not operating if ventilation system is operating);

(v) Moisture from combustion of hydrogen fuels used in cooking, lighting or refrigeration: and

(vi) Moisture from bathing or showers.

(2) Heat Transfer Throuuh EOC Boundaries. Tests have shown that for underground or partially underground EOC's, cooled by fresh air ventilation, as much as 30 percent of the heat generated in .the EOC was dissipated by transfer to the surrounding earth. The amount of heat which can be transferred in this manner depends, of course, on many factors and must be determined for each individual EOC facility by a qualified mechanical engineer. It can, however, have a significant effect on required ventilation rates. In analyzing the EOC thermal system, the following factors would be considered as affecting, or being affected by, the physical environment.

(a) The size and shape of the EOC with respect to surface area, volume, geometry and exposure:

(b) The number of occupants:

(c) The duration of occupancy:

(d) The metabolic characteristics of the occupants in relation to energy expenditure, sensible and latent heat losses, oxygen consumption, and carbon dioxide production;

(e) The physiological and psychological reactions of the people to the immediate situation;

(f) Clothing (insulating properties, absorptivity);

(g) Diet (solid and liquid, including drinking water):

(h) The temperature, humidity and air motion in the EOC space (Effective Temperature);

(i) Interior surface temperatures and moisture condensation:

(j) Temperature and humidity of air leaving the EOC;

(k) Interior heat and moisture sources other than people:

(l) Heat flow from adjacent structures or heat sources;

(m) Thermal properties of the EOC and surrounding materials (conductivity, density, specific heat, diffusivity, moisture content);

(n) Thickness and thermal properties of shielding materials:

(o) Weather conditions with respect to variable temperature, humidity, solar radiation, wind, and precipitation:

(p) Initial conditions of the EOC environment and its surroundings (temperature distribution, moisture);

(q) Temperature and humidity of fresh air or air supplied to the EOC space;

(r) Rate and method of ventilation with fresh and recirculated air (cooling, heating, and air conditioning): and

(s) Required degree of reliability.

(3) Cooling bv Ventilation. An analysis of the transient heat and moisture flows for an EOC can be performed if sufficient data are available. Such data would include:

(a) Ambient temperature and humidity, wind velocity and direction, latitude and cloud cover;

(b) Ventilation rate;

(c) Number of occupants and their metabolic rates:

(d) Physical and thermal properties of the EOC, adjacent structures and surrounding soil;

(e) Heat and moisture absorbed by mechanical cooling equipment, if any: and

(f) Heat and moisture dissipated by internal equipment.

(4) Natural Ventilation. Natural ventilation depends on difference in density of the air or wind forces, rather than mechanical power to move air. It would be most applicable to buildings which have large openings and passageways which would permit the movement of large quantities of air with small differences in density and pressure.

(a) In general, EOC's would not have large openings and passageways. Therefore, except in very unusual circumstances, natural ventilation would not be a feasible method of ventilation for an EOC.

(b) It is possible that an EOC without blast protection could be located on the upper floors of a large building. In this case, some natural ventilation might be possible. However, the thermal environmental criteria for an EOC could be met with natural ventilation (or with powered ventilation) only when outside weather conditions were favorable. During other times, mechanical cooling or heating would be necessary and mechanically powered fans or blowers would be part of the heating and cooling system. Thus, the EOC would not depend on natural ventilation.

(c) FEMA's approved method of determining the number of people that could be supported by natural ventilation may be used when a natural ventilation analysis is relevant to the EOC design.

(5) Air Distribution. A cooling and heating system will almost certainly be required in an EOC. Therefore, air distribution will be by ductwork with appropriate outlet grills or diffusers in the various spaces to be ventilated. Air distribution would follow accepted air-conditioning practice since the conditioned air would be distributed to maintain the desired temperature and humidity for each space in the EOC.

(6) Mechanical Air Conditioning. The most positive control over the thermal environment can be attained by use of a mechanical air-conditioning system and, in most cases, this would be the system best suited for use in an EOC. Within the design capacity of the system, the conditions in the EOC can be controlled and varied to meet changing conditions and needs. There are two methods of securing a refrigeration effect by mechanical means: the vapor-compression system and the absorption system. The vapor-compression system is the most widely used. Either method, however, would require the on-site availability of emergency power and fuel.

(7). Heating Systems. During cold weather it will be necessary to provide a method of heating the EOC in order to maintain the desired thermal conditions. In a typical emergency shelter, fallout shelter for example, this might not present a very severe problem since lower Effective Temperatures can be tolerated and the human metabolic heat under crowded conditions may be sufficient to meet the criteria. In an EOC, on the other hand, low effective temperatures would not be tolerated and conditions would not be crowded enough for the metabolic heat to supply the necessary heating effect. There is a wide variety of possible heating systems which might be used. These include:

(a) Air recirculation;

(b) Waste heat recovery:

(c) Conventional heating systems: and

(d) Heat pumps.

(8) Air Recirculation.

(a) In mild or cool weather, mixing fresh air with recirculated air may be sufficient to provide the necessary heating requirements of the EOC. Recirculated air will have been heated by the human metabolic load and heat from lights and electrical and mechanical equipment. By adjusting the proportion of fresh air to recirculated air, the required conditions might be met. If, however, it were.necessary to reduce the fresh air below 3 cfm per person, the chemical composition of the air would deteriorate. Thus, in cold weather this system would not be adequate to meet the requirements.

(b) In most locations in the United States, the weather will be cold enough during the winter months to require heating beyond that which could be accomplished by air recirculation alone. There are a few locations, however, where it might be sufficient such as along the south Gulf coast in Texas and in South Florida. In Key West, Florida, for example, it is unlikely that there would be any time when more than tempering of the air would be required.

(9) Waste Heat Recovery.

(a) In any EOC there will be heat produced which must be removed when cooling is required. These same heat sources can be used for heating in cold weather. Already mentioned is the heat from lights, electrical equipment, and mechanical equipment. The most likely source of waste heat, however, would be the heat rejected by the engine driving the emergency generator.

(b) Of the heat produced by the combustion of fuel in an engine, 30 percent or more is rejected in the exhaust. A heat exchanger on the engine exhaust can be used to recover some of this for heating the ventilation air. This could be a direct heat transfer from the exhaust gases to the air to be heated or could be heat transfer to water which is then pumped to a heating coil over which the air is blown.

(c) If direct heat transfer from exhaust gases to ventilation air is used, great care must be exercised to ensure that there is no leakage of exhaust gases into the air. The components in engine exhaust gases, especially carbon monoxide, could be deadly if they were to mix with the ventilation air.

(d) In most cases it would be easier and more convenient to use the waste heat to increase the temperature of water and then use the water in a heating coil. Leakage from the exhaust into the water would be highly undesirable but would not be dangerous to the lives of the occupants. It is easier to pump water from one place to another than it is to move air. Smaller passageways are required and it requires less power. If the cooling system uses chilled water and a cooling unit, it is probable that the same coil could be used for heating merely by pumping hot water through it rather than chilled water.

(e) When transferring heat from the engine exhaust, care should be taken not to reduce exhaust temperatures too much. Water vapor, formed by the combustion of hydrogen in the fuel, will condense if the temperature is reduced below about 212*o.F. The water can then cause rust in the exhaust system. Worse yet, any sulphur in the fuel forms sulphur dioxide when it burns. Sulphur dioxide combines with water to form sulphuric acid which would be highly corrosive in the exhaust system.

(f) In addition to the heat rejected in the engine exhaust, another 20 to 30 percent of the heat of combustion is rejected in the engine cooling system. This could be another source of heat if the necessary heat transfer components are provided. However, the engine coolant leaves the engine at a relatively low temperature as compared to exhaust gas temperatures; and, therefore, the amount of heat available and the effectiveness of the heat transfer would be much less.

(10) Conventional Heatina Systems.

(a) There are many types of heating devices and systems available commercially. An analysis must be made to determine which would best suit the requirements for the EOC, including such factors as the capacity required, available fuels, space for equipment and warm air distribution, requirements for combustion air, requirements for chimneys and vents, operating procedures and requirements, maintenance requirements and costs, operating safety and cost of installation and operation.

(b) A key factor in an EOC will be the availability of fuel. The fuel for the heating system must be stored in or near the EOC since availability of natural gas from a pipe line or electric power from public utilities would be highly questionable. Fuels which can be stored on the premises would include coal, fuel oil and liquified petroleum gas. Of these, coal can probably be eliminated on the basis of the large volume of storage space required and the costly and bulky equipment required for handling and automatic firing, or the requirement for manual firing. Also, coal is not adaptable to other fuel requirements such as in an internal combustion engine.

(c) It would be convenient to store only one fuel which could be used in both the heating system and as an engine fuel. The fuels likely to be used for the prime mover in the emergency engine-generator would be gasoline for a spark ignition engine, number 1 or number 2 fuel oil for a diesel engine, or liquified petroleum gas (LP gas) for a converted gasoline engine. Of these, gasoline would not be suitable for use in a heating system. Thus, the most likely fuels would be fuel oil or LP gas.

(d) Heating devices burning fuel oil or LP gas might be either boilers or furnaces. A boiler uses the heat of combustion of the fuel to produce either steam or hot water. The steam or hot water is then distributed to heat exchangers across which the conditioned air is blown.

(e) Space heaters are not recommended for EOC's.

(f) Warm-air furnaces would usually be the most simple and economical installation for an EOC. They are readily available in almost any required size in factory assembled units. Installation consists principally of connecting to fuel lines and flue gas passages and electrical connections for the controls. Their chief disadvantage would be the relatively large space requirements for distributing the heated air to the conditioned space. In the usual case this would be through ductwork with forced air flow powered by a blower in the furnace unit. The same duct system is normally used for distributing cooled air in air-conditioned facilities.

(g) Steam or hot-water boilers are also available as factory-assembled units in almost any size required. Boilers operating at pressures above about 15 pounds per square inch gauge (psig) for steam or about 160 psig for water, are commonly referred to as high pressure boilers. They are available to be fired by coal (either manually or by stoker), oil, electricity, or gas. Many are designed to burn more than one fuel. It would thus be possible to obtain one which burned, for example, natural gas during normal EOC operating conditions, but could be switched.to fuel oil or LP gas during emergency operations.

(h) One of the principal advantages of a steam or hot-water boiler is that the distribution of the heated medium is in pipes of relatively small diameter rather than ducts, thus saving space and fabrication costs of the ductwork. Heat is transferred to the conditioned space by coils which can be in the space or in the ventilation air passages leading to the space. If cooling is accomplished by a chilled-water system, hot water from the boiler can be circulated through the same coil. Change over from heating to cooling involves only changing the water circuit.

(i) In a blast-protected EOC facility, a chilled-water cooling system and hot-water heating system may have some advantages. The refrigeration and heating units can be located in the mechanical equipment room separated from the living and working space. The only connection would be the hot and cold water pipes to the heat exchanger in the conditioned space. The piping is relatively strong and should be able to survive dislocations and accelerations caused by blast loadings if the necessary flexible connections, hangers and expansion loops are provided. The heating and cooling units are compact and can be provided with shock mounts so that they would move as a unit under ground shock loading. Flexible connections for the fuel, water, and electrical lines could accommodate this movement.

(j) Electric heat meets many of the requirements for heating in an EOC. It requires no combustion air and no chimney or vents. It produces no exhaust gases which could be dangerous, and it uses no oxygen. The equipment is relatively inexpensive and takes up very little space. Baseboard or panel electric heaters in the conditioned space eliminate the need for ductwork to move warm air from the heater to the heated space. It is safe to operate and is easily maintained. Finally, the conversion of energy stored in the fuel to electricity is comparatively inefficient when the net result is heat. More heat can be obtained by using the heat of combustion of the fuel directly than by converting the heat to electrical energy and then back to heat.

(11) Heat Pumps.

(a) Any refrigeration cycle absorbs heat at a low temperature in the evaporator and rejects heat at a higher temperature in the condenser. It "pumps" heat from a low temperature to a high temperature and thus could be called a heat pump. In the context used here, however, a heat pump is a refrigeration cycle used. for heating purposes. In the usual case, a heat pump is used for both heating and cooling according to the demand. In the cooling mode the heat absorbed at the evaporator is used for refrigeration effect. In the heating mode the heat given up at the condenser is used for the heating effect.

(b) The change from the cooling mode to the heating mode can be accomplished by changing the flow of refrigerant, or changing the flow of air. When the flow of refrigerant is reversed, the evaporator coil becomes the condenser and the condenser coil becomes the evaporator. In the second case, the air to be conditioned is caused to flow across the condenser coil for heating or across the evaporator coil for cooling.

(c) Heat pumps may be classified according to the type of heat source and heat sink used. In the types of heat pumps identified below, the first term is the source, and the second is the sink or medium to be heated.

(i) The most common heat pump is the air to air type. This type uses the atmospheric air as the heat source, and the heat sink is the air to be heated. The usual method of changeover from cooling to heating is by interchanging the air circuits by means of dampers, either motor-driven or manually operated. With this system one heat exchanger coil is always the condenser and the other is always the evaporator. The conditioned air passes over the evaporator during the cooling cycle and the outdoor air passes over the condenser. During the heating cycle the indoor, conditioned air passes over the condenser and the outdoor air passes over the evaporator.

a. As the outdoor temperature goes down, the heating capacity of the heat pump decreases. In order for heat transfer to occur, the outdoor air temperature must be above the refrigerant temperature in the evaporator. As this temperature difference becomes smaller, the rate of heat transfer per unit of heat transfer surface decreases. Therefore, the surface area of the evaporator coil in an air-to-air heat pump is normally larger than is required for the cooling cycle.

b. When the temperature difference between the-outdoor air,and- the refrigerant becomes too small, heat transfer will not be possible and the heat pump will not provide any heating effect beyond that provided by the energy input of the compressor. Most commercial units provide a booster heater, usually an electric resistance strip, which will provide heat when outdoor air temperatures get too low. This would not be advantageous in an EOC when electrical power is from an emergency generator, but could be done if the generator capacity is adequate to handle the heating load when outdoor air temperatures go down.

(ii) A water-to-air heat pump uses water as the source of heat and air as the sink. Air is used to transmit heat to or from the conditioned space. Water may be obtained from city water supplies, wells or surface water. City water offers many advantages but even during normal operations it would probably be prohibitively expensive to use. During many emergency conditions it would not be available at all and, therefore, could not be considered for use in an EOC. Surface water would rarely be available in sufficient quantity and, if available, could be subject to freezing in cold weather. Since it is so rarely used, standard designs are not available for equipment and application. Individual design would be necessary. Thus well water is normally the only feasible source.

a. Water from a nonthermal well can represent the ideal heat source. Since it remains at the same temperature winter and summer, the design of heat transfer components is simplified. Also the heating capacity would not decrease as outdoor air temperatures go down.

b. During the cooling cycle, using the water-to-air system, a conventional water-cooled condenser is used. During the heating cycle, the flow of refrigerant is changed so that the condenser becomes the evaporator, absorbing heat from the water. The air to be conditioned always passes over the same heat transfer coil.

c. Although the use of water as a heat source is advantageous from the standpoint of heat transfer, it has other disadvantages. It is dependent on well water being available in sufficient quantity from a well of reasonable depth. For normal application the cost of the well greatly increases the installed cost of the system. In an EOC where the well is required as an assured source of water, this may not be a serious disadvantage since the cost of the well is an unavoidable expense and should not be charged entirely against the cooling-heating system.

d One principal dis- advantage of the water-to-air heat pump-is that there must be a means of disposing of the water after it is used. During the heating cycle the water is cooled as heat is absorbed from it and it may be suitable for use in cooling the engine-generator. During the cooling cycle, however, the water is heated by the condenser and may become too hot to be effective for use as an engine coolant. In either case the heat pump may use more water than could be used for engine cooling. Also the water still must be disposed of after passing through the engine cooling system.

e. Water can be disposed of in a storm sewer, into a natural or artificial catch basin, by discharging it into a nearby river, stream or lake, or by pumping it into a dry well. Many municipal codes prohibit disposal of water from a heat pump into the sewer system so this could not be used during normal operation. During emergency operation the sewer system may not remain in operation. The availability of natural catch basins, rivers, streams or lakes would, of course, depend on the location of the EOC relative to these natural features. Environmental considerations may also prohibit disposal of heated water into bodies of natural water.

f In some commercial applications, and a few residence waste water from a water-to-air heat pump is disposed of by pumping it into an irrigation system for the landscaping surrounding the building. This, of course, involves additional cost for pumps, piping and sprinklers for the irrigation system. Whether or not it would be feasible to use this method of disposal for an EOC would depend on many factors. An analysis would have to be made for the individual installation. For a blast-protected EOC facility, the analysis must take into consideration whether the system could survive the blast effects in operating condition.

g. An artificial catch basin could be used only if sufficient land area is available and if drainage from the basin can be created. The cost of constructing the catch basin would, of course, be a major consideration.

h. In many installations a dry well will be the only feasible method of disposing of the waste water. This has the advantage of returning the water to the underground reservoir and helps to maintain the water table. If the heat pump is to be used during normal operations on a day-to-day basis, this method of disposal should be seriously considered since the water reservoir could otherwise be depleted over a period of time. The cost of the dry well would, of course, be an additional cost for the system.

(iii) An air-to-water heat pump is similar to the air-to-air system in that the source of heat is atmospheric air. However, instead of heating air directly by passing it over the heat exchanger, water is heated in the exchanger and pumped through a heating coil over which the air is passed. In this case the water operates in a closed cycle and no make-up or waste water disposal is necessary. Changeover from cooling to heating is accomplished by reversing the flow of refrigerant through the two heat exchangers.

(iv) A water-to-water system is similar to the air-to-water system, except that the source of heat is water from a well or other source. The heating-cooling changeover may be accomplished in the refrigerant circuit, as in other systems, but is often performed by switching the water flow from the chiller (evaporator) to the condenser and vice versa.

(v) Earth-to-air and earth-to-water systems are similar to the other types except that the earth is the source of heat during the heating cycle and the sink during the cooling cycle. Heat transfer is through coils buried 3 to 6 feet below the surface of the earth. Such systems have not been widely used due to high installation expense, ground area requirements and uncertainty of predicting performance. The heat transfer properties of the soil depend on its thermal properties which are functions of soil composition, moisture content, etc. These can change with time, especially the moisture content. Design information for systems using earth as the source or sink is not easily obtainable.

(12) The Final Selection of the Coolina and Heatina Svstems.

(a) The selection of cooling and heating systems for an EOC will depend on many factors including the location of the EOC, possibility of nuclear weapons' effects, characteristics of the site, weather conditions to be expected, internal heating and cooling loads, availability of water from wells or other sources, the type of emergency engine-generator selected, availability and storage capacity required for emergency fuel, installation costs and operating costs.

(b) In most cases the cost factor will be the dominant consideration and budget limitations may well cause some compromises which result in a less-than-ideal system. The A/E should complete the necessary studies and select the heating and cooling systems early in the design phase so that their impact on the budget can be assessed.

h. Filters. The general categories of materials which might have to be removed from the air would include normal atmospheric dusts and airborne contaminants. This might include pollutants resulting from industrial processes, in some cases: abnormal quantities of dust resulting from the detonation of nuclear or conventional weapons: and radioactive fallout particles. Only the latter two categories are addressed here. Other appropriate agencies should be consulted when considering contaminants such as chemical and biological agents and gaseous contaminants similar to those associated with a nuclear power generator accident.

(1) Filter Selection. The air filter selection will depend on the type of protective EOC facility, its location, and mission. The principal hazard would be radioactive fallout for an EOC located in an area which will not be affected by the direct effects of a nuclear detonation.

(2) Filtering Fallout Particles.

(a) The amount of fallout carried into a shelter by natural ventilation will rarely constitute a hazard to the occupants. This is true even if the air is not filtered. On the other hand, some forced ventilation systems may require design attention to keep fallout particles from entering.

(b) If the ventilating system opening is horizontal, and the air enters upward, particles having a terminal velocity greater than the velocity of entering air will be excluded. If the opening is vertical and faces into the wind, particles may be blown through the opening even though the intake velocity is very low: in fact, the large openings typically used to obtain a low entrance velocity may tend to increase the particles entering the system.

(c) Air filters, washers, or scrubbers can be more efficient in removing particles, but the additional cost for such systems may be a concern. In an EOC where a high PF (PF-100 or greater) is required, the radiation contribution from particles entering through the ventilation openings may significantly reduce the protection factor justifying the increased cost for keeping them out.

(d) Separation of fallout particles from the air is promoted by the configuration of the inlet fixture and a low intake velocity.* Low intake velocities, however, require larger face areas at the inlet. The larger openings can present difficult problems in radiation shielding and are even more difficult to protect against blast effects. Thus, it may be more feasible to use smaller openings with higher intake velocities and install a filter to remove any particles which would be entrained in the ventilation air. It would also be necessary to consider that the filter could be a source of radiation as the fallout particles accumulated on it, and therefore shield the filter from the occupied spaces.

(e) An alternative would be to consider the possibility of using several small inlets with low intake velocity rather than one large one. Although this might increase the cost, it offers certain offsetting advantages for nuclear attack protection.

(i) The gravity separation characteristics of low velocity intake is retained without requiring large apertures in the shielding structure. In general, it is easier to shield several small openings than one large one.

(ii) Location of the air inlets on different sides of the building increases the possibility that one of them will be on the lee side and will, therefore, receive less fallout.

(iii) With several small inlets, one inlet could be damaged or blocked by blast, seismic activity, collapse of structures, falling trees or accumulated debris: and ventilation could still be maintained, although at reduced capacity.

(iv) If separate blowers are installed for each inlet, the cost will be increased but the system would have more flexibility and failure of one unit would not result in the loss of the entire ventilation capacity.

(3) Effects of Dust Loads on Filters (Blast Hardened EOC's).

(a) The air cleaning system for an EOC located in a risk area must take into account the possibility of greatly increased dust loads, as well as the direct effects of a nuclear weapon on the filter system. After a nuclear detonation, it is quite probable that there will be large quantities of dust suspended in the air. The dust cloud could well last for several hours, quickly loading the facility's air filters to capacity for both generator combustion air, heating, ventilation, and air conditioning fresh air intakes. There are two basic approaches to dealing with the dust problem. If operational requirements of the EOC permit, the best approach is to shut off the air flow from the outside from the time immediately after the nuclear blast has occurred until most of the outside dust has settled. Otherwise, provisions for adequate filtering must be made.

(b) One filtering option is to provide a prefilter to remove the large dust particles and a portion of the smaller particles in order to presence the capacity of the main filters, particularly if these are the high-efficiency type. The prefilters would be medium to low efficiency, disposable, panel types, either dry or viscous coated, with a large dust-holding capacity. A few spare sets would need to be kept on hand to replace them when they become loaded. Even if the prefilters are used, the dust passing through them would still collect on the main filters. Both could become a source of radiation and should therefore be shielded from the occupied space.

(c) A moving curtain filter is another possibility since this would continuously feed fresh filter media into the air stream. The contaminated media would be stored on the take-up roll until it was safe to dispose of it.

(d) A third possibility would be to install a reserve set of filters in a by-pass duct. The incoming air is diverted to the by-pass when the main filters become loaded. This can be done by remotely activated dampers. The by-pass duct and damper system would add to the cost of the installation, but may be less expensive than the other alternatives.

(e) Dust loads up to 3 grams per cubic foot may result from the destruction of buildings due to air blasts. The heaviest portion of the dust load will have particles in the size between 5 and 100 microns.

(4) Weapons' Effects on Filters (Blast Hardened EOC's).

(a) Filters are either immune to or are protected from most weapons' effects by normal good design practice, except for the effects of ground shock and blast overpressure.

(b) The effect of ground shock on air-cleaning devices will be relatively unimportant, except for the electrostatic types which depend on precise alignment of lightly supported parts and on electronic tubes. (Electronic tubes, transistors, and circuits are also highly vulnerable to damage by the EMP.) However, it is highly improbable that expensive electrostatic filters would be used in an EOC.

(c) The effect of ground shock on the filter mountings and ductwork must be considered. Distortion of the mounting could allow air to leak around the filter and thus circumvent its usefulness. Leaks in the ductwork, resulting from distortion, on the upstream side of the filter could allow unfiltered air to contaminate the space through which the duct passes. Flexible connections between the duct and the filter mounting can help prevent distortion by accommodating differential movement resulting from ground shock. Flexible connections and hangers on the ductwork will permit movement of the duct without creating leaks at the joints.

(d) The effects of blast overpressure on the filters can be more serious. An overpressure of 2 psi will cave in common panel filters and severely damage even the high-efficiency type built to military specifications. The pressure wave must also be prevented from entering the EOC, since the same overpressure would cause significant injuries to the occupants. The blast overpressure can be attenuated by combinations of right-angle turns in the air passages and/or by the use of expansion chambers. However, a blast valve used to close off the ventilation intake during the overpressure phase is more effective and requires less space.

(5) Filter Installation.

(a) The filter frame should be sealed adequately by a good latching mechanism in the duct and the cells sealed in the frame, in order to prevent leakage around the filter.

(b) The usual recommendation is that the filter be installed on the upstream side of the blower. This works some hardship on the blower, since the filter is on the suction side rather than the discharge side, but it will prevent possible contamination of the blower. It may be desirable to locate the duct section containing the filter in a protected space which is pressurized by the blower discharge. Any leakage which might occur would then be from the space into the duct. If only a medium-efficiency filter is used, this would not be necessary: but it is a good precaution for more sophisticated installations.

(c) Regardless of the type of filter installed, it is desirable to oversize the filter system wherever possible to reduce the pressure drop across the filter and decrease the power requirement. The filter would also have a greater dust-holding capacity and, therefore, a longer useful life. Or, looking at it another way, increased occupancy due to larger EOC staffing during an emergency justifies oversizing the filter system.

(6) Filter Maintenance.

(a) Since the EOC is a dual-use facility, and is occupied during nonemergency conditions, the question of good filter maintenance practice is slightly more complicated than for normal facilities. In normal use, filters are allowed to operate until they near the end of their useful life, for economic reasons. In an EOC, economy may have to be sacrificed in order to ensure-that-.-the system is always ready for emergency use. There are several possible approaches to this problem.

(b) A set of clean filters may be kept on hand and placed in service when the emergency occurs. The effectiveness of this approach will depend on how long it takes and how difficult it is to change the filters. Replacement media are, in most cases, sufficiently inexpensive and occupy little space. In any case, it is good preparedness practice to keep spare filters on hand in case of some unforeseen difficulty.

(c) Separate filters for emergency use can be kept installed, but by-passed during normal operation to prevent premature use. This could be a more expensive installation and may not be 100 percent effective even with tightly closing dampers.

(d) For vital day-to-day operations, it may be desirable to operate a higher quality filter system at all times in the EOC. Under these conditions, it would be necessary to establish more intense inspection and maintenance procedures for the filter system than the routine for a normal facility.

i. Water Requirements. An assured source of water is a basic requirement for an EOC. Water is absolutely essential to human survival and is necessary, or highly desirable, for other purposes. The water requirements may be divided according to the need for potable water and nonpotable water.