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Member ASHRAE

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The aim of the HVAC design is to provide a comfortable and healthy environment for the building occupants at a minimum cost. Although this definition applies to all kind of occupancies, the design of a hospital is more challenging because many of the hospital spaces present a health risk, and the elimination or the reduction of these risks through the HVAC systems should be addressed as well.

The comfort can be achieved by controlling the temperature, the humidity, the air movement, and the level of noise. In hospitals, the temperature and humidity could become factors in patient therapy.

A healthy environment can be attained by minimizing the risk of contamination thorough adequate air distribution, directing the flow of air from less contaminated space to the more contaminated space, evacuating the pollutants as close as possible to the source, introducing the minimum outside air to every space of the building, and cleaning the air through filtration and other cleaning devices.

These conditions can be achieved at all times by designing systems that are reliable, not only during normal operation, but also during unusual or catastrophic events and are adaptable to future changes and easy to be maintained.

A minimum cost can be accomplished by reducing each of the cost elements: investment cost, annually recurring operation costs, such as energy and maintenance; future nonrecurring costs, such as spare parts and replacements; future nonrecurring costs due to occupancy changes.

To achieve all these goals, the design should be approached in a systematic manner, by defining the design criteria at the beginning of the project during the planning phase and selecting the HVAC systems based on life-cycle cost analysis.

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Heating, ventilating, and air-conditioning systems are critical to the operation of health care facilities that cannot function unless the HVAC systems work.

The aim of the HVAC design is to provide systems that control the indoor environment and ensure a comfortable, healthy, and safe environment for the building occupants at a minimum cost.

Comfort can be achieved by controlling the temperature, humidity, air movement, and level of noise.

A healthy and safe environment can be attained by achieving good indoor air quality, which entails introducing minimum outside air to every space of the building, cleaning the air through filtration and other cleaning devices, removing airborne contaminants as close as possible to the source, and providing adequate air movement for contamination control.

In hospitals, the air-conditioning systems can play an even more important role; they can contribute to the therapy of the patient. A cool and dry environment for cardiac patients and patients with head injuries, brain operations, or suffering from hyperthermia, or a warm and dry climate for rheumatoid arthritis patients, or a warm and humidified environment for those with chronic pulmonary disease, with burns, and for those requiring oxygen therapy are only few examples of such therapeutic, beneficial effects attributed to the controlled environment.

The environmental conditions can be achieved at all times by designing systems that are reliable during both normal operation and catastrophic events, flexible to future changes, and easy to maintain.

A minimum cost can be accomplished by reducing each of the cost elements: investment cost, annually recurring oper-

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ation costs, such as energy and maintenance, future nonrecurring costs, such as spare parts and replacements, and future nonrecurring costs due to occupancy changes.

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Each architectural firm follows its own project process. Traditionally, the design is performed in five phases: master plan, design program (predesign), schematic design, design development, and construction documents. These five phases are usually followed for large projects but are condensed into three phases for smaller projects: schematic design, design development, and construction documents. Other firms conduct their architectural practice in more than five phases of project process.

The phases of design are usually established by the architect with formal submissions according to the owner's needs, established through contracting.

The starting point of the HVAC engineer is determined by the architect. The involvement of the HVAC engineer in the process design at the beginning of the design process is very important for the quality of the project, the timely delivery, and the cost-effectiveness of the project. This has to be clearly communicated to the architect during the contracting phase.

Following are notable tasks of the design process. These tasks are important in attaining a good design in a timely and cost-effective manner.

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Regardless of when the HVAC engineer starts work, in the program phase or the schematic design phase, he/she must first establish the design criteria specific to the building and its location.

First the engineer has to collect, review, and analyze project data through site visits, interviews with key personnel, and interaction with other disciplines. Second, the engineer has to analyze all applicable codes, compare them, and select the most stringent code requirements. Most of the time, the code requirements are minimum requirements and standards or other publications surpass the codes in their recommendations.

Following good engineering practice, sometimes above the code requirements, is an advisable approach required by the professional engineering licensing board and accepted in the court of law.

The design criteria must be completed, documented, and presented to and signed off by the architect, the owner, the operator of the building (if there is one), and any other entity with whom the engineer (or the architect) has a contractual relationship. This will achieve two purposes: it will set the targets of the design and it will offer protection in case of future litigation.

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The HVAC conceptual design is part of the design process in which the potential HVAC system alternatives are generated and compared. The most cost-effective alternative is selected and integrated into the building systems. The conceptual design starts in the predesign phase after the design criteria are established and ends with the selection of the best alternative, the process being formalized into a schematic design report.

Based on the design criteria, the HVAC engineer must analyze building location, climate, orientation, configuration, occupancy and space functions, building characteristics, and owner's capabilities for operation and maintenance and establish the system alternatives that can do the job. Then, the engineer will proceed to the analysis and preliminary selection of HVAC systems. This first selection is usually done based on experience and leads to the selection of two or more alternatives to be further analyzed and compared. The final selection of alternatives should be done based on life-cycle cost analysis as further detailed. The procedure could be applied to the entire HVAC system, to a portion of the system, or to building elements.

The selection of the HVAC systems should occur in the early phases of design and should be fully integrated and coordinated with the building's other systems.

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Quality control is essential for any design process. Besides the regular quality control performed within each design organization, an independent evaluation of the project conducted through the design peer review process is recommended.

The design peer review can be initiated by public or private owners, designing firms, or private developers.

The owner will benefit through the assurance that the project will achieve its objectives, the design is conceptually correct, the design documents are accurate, adequate, and complete, costly change orders are avoided, and the requirements of public safety and health are met.

If the design peer review is initiated by the architect or by the HVAC designer of record, he/she will benefit by providing better services to the owner. Design review offered by the architect or HVAC engineer could represent a good marketing tool promoting the quality of their services.

The peer design review recommendations must not supersede the original design professional's opinion in the case of disagreement between the two professionals. The responsibility for the project design remains with the design organization. However, if the original designer does not consider the reviewer's recommendation to be the best alternative, yet finds it to be harmless, the engineer may implement it at the owner's or architect's request and acceptance of the extra cost and other effects that might occur. If the reviewer finds serious design problems that the responsible design engineer disagrees with or refuses to change, the owner or architect should seek advise from other experts. At this point, it is the owner's or architect's responsibility to solve the matter in an

ethical and legal way, keeping the design reviewer free from loss or damage.

To be cost-effective, the design peer review should be performed in all phases of design, and most importantly, it should start early in the design process. It should be performed by highly qualified individuals with experience in the type of project reviewed.

The design peer review does not include value engineering studies and/or construction cost estimates. It is not a constructibility review, although constructibility issues could be part of some peer reviews.

The design peer review should not be regarded as a reflection on the professional capability of the design team. It is just an objective look, from a different perspective of an independent, competent, experienced professional with a trained eye. The final goal is to enhance the quality of the design.

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After defining the systems, a value engineering effort may be planned. Value engineering, defined as an effort to save money without jeopardizing quality or performance, is recommended to be performed only in the early phases of design. It is not recommended during construction documents or afterwards.

Value engineering can be performed by either the members of the design team, the design peer reviewer, or another design professional hired for this purpose.

Through value engineering, alternative design solutions are suggested and evaluated. The suggestions are recommended for implementation based on an analysis that includes their life-cycle cost, performance, reliability, and conformity with the project design criteria.

Used wisely, value engineering can be a powerful tool in reducing the life-cycle cost of the project while maintaining quality.

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Criterion is defined as a measure of value. In this context, the design criterion represents the measure of what we want to achieve by the HVAC design, the aim of the design, and what is expected from the design.

As previously stated, design criteria should be established in the programming and schematic design phase. As Seneca said, "Our plans miscarry because they have no aim. When you don't know what harbor you're aiming for, no wind is the right wind." To paraphrase, no design is the right design until we know what we want to achieve with our design.

Following are comments pertinent to the most important issues faced by the HVAC engineers in the selection of the design criteria.

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Outdoor air temperature and humidity, wind, and other climatic information (clearness number, ground reflectance) have to be well defined for accurate cooling/heating load calculations.

For the outdoor air temperature and humidity, the designer should use the published temperature and design data for the closest location to the project site. However, he/she should also collect data and analyze the specifics of the local climate that might not be reflected in the published data of the nearby location and subsequently modify these data.

For the design operating conditions of the cooling towers, it is always prudent to increase the design dry-bulb temperature by few degrees, depending on the location of the tower and the surrounding surfaces. For example, the temperature on roofs (especially if they are of dark colors) increases substantially during summer sunny days.

Another outdoor condition that would significantly affect the design is the quality of outdoor air. The outdoor air quality has an impact on the filtration or other design methods necessary to provide the required indoor air quality. Knowing from the beginning if the outside air is dusty or if there are frequent sand storms in the region not only leads to an adequate design, but considering it from the inception of the project, rather than introducing it afterward would save time, effort, and money.

The proximity of the building to sources of gaseous contaminants could have either a limited negative impact that can be solved by positioning the outside air intakes far from these sources or an overall negative impact affecting the entire building, in which case either the location of the building may well be changed or adequate filtration must be provided.

The direction of the prevailing winds could significantly influence the design of the exhaust systems (point of discharge, type of discharge, and velocity) in relationship with the position of the outside air intake.

The final figures for outdoor conditions should be clearly shown and justified in the formal design criteria submission.

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Temperature and Humidity. Temperature and humidity are not only the most important elements of comfort but also important factors in the proper operation of the spaces and even in the healing process. Their values must be correctly defined for each space and coordinated with the architect, the programmer, and the user of these spaces.

Of significant importance are the special conditions of temperature and/or humidity for the prevention and treatment of diseases. Sometimes the architectural program cannot specifically define where special temperature and humidity conditions will be required in a row of rooms having the same type of occupancy, for example, a patient room occupied by a patient requiring special temperature and/or humidity conditions to match a specific illness. These rooms, although not

specified as such in the architectural program, should be designed with capability for larger deviations from the standard temperature and humidity in order to accommodate these special requirements that might occur at random.

This is the case where each room cooling/heating load must be calculated for the maximum conditions, but diversity factors must be applied for the calculation of the simultaneous loads of the entire area.

Temperature and humidity also play an important role in survival of airborne microorganisms. However, their environmental dependency is so diverse from one microorganism to another, it makes it impractical to be considered in the design of the HVAC systems.

Summer/winter temperatures and humidity, high and low limits, must be established for each type of occupancy, published, and approved within the design criteria package.

Air Quality. The final air quality that is achieved in indoor environments depends on a multitude of factors: location and intensity of the contaminant sources, contaminant capture as close as possible to the source, their transport by the air movement in the space or through the HVAC system, and their removal by exhaust, by filtration, or other means of removal or eradication.

Most of these requirements are developed and achieved during design, but initial conditions and final goals must be established as design criteria.

For each type of occupancy, the contaminant source must be established. The indoor-generated contaminants can be those created by the occupants' activities, such as photocopying, laser printing, and cooking, those that out gas from manufactured construction materials or cleaning products, or microbial contaminants carried and released by patients or grown in or on various building elements. For each type of occupancy, ventilation requirements as prescribed in the current codes must be determined.

The spaces requiring a protective environment must be defined and HEPA filtration must be prescribed. The airborne infection isolation rooms and other rooms requiring exhaust must be also defined and ventilation rates determined. The assessment of the need for ducted return instead of plenum return that would eliminate the risk of above ceiling plenum contamination for some areas of the facility must also be included in the design criteria.

Ventilation Rates. The ventilation rates expressed as either air changes per hour, volume flow rate per unit of area, or volume flow rate per person dictate the quantity of outdoor air to be delivered to a space in order to assure adequate dilution of pollutants and an acceptable indoor air quality.

For health care facilities, the ventilation rates assure the control of the airborne disease transmission as shown below.

The ventilation rates are prescribed in ASHRAE Standard 62-1989, recommended in guidelines, and mandated by the numerous current codes applicable sometimes concomitantly to the same territorial jurisdiction. Unfortunately, there is no uniformity of ventilation rates across the U.S., and the designer must consult and compare several sources to define the most stringent requirements for the ventilation rates.

Air Movement and Pressure Relationships for Infection Control. Consistent airborne infectious control can be achieved through a careful balance between the air that is moving into the room and the air that is moving out of the room. This is based on the principle that the air should move from the clean area to the dirty one. This is either for protective environment rooms, such as operating rooms, bone marrow transplant/high risk oncology, labor and delivery, trauma, X-ray catheterization, radiation oncology, sterile storage, and processing, or for airborne infectious isolation rooms, such as emergency, intensive care, convalescent, sputum induction, bronchoscopy, and laboratories (Streifel and Marshall 1997).

To maintain the airflow in the desired positive or negative direction, pressurization must be achieved through the difference between the incoming and outgoing airflow. The relationship between the differential airflow and the resulting differential pressure depends entirely on the room's total leakage area.

Several authors have prescribed differential pressure figures that have to be maintained to achieve unidirectional airflow. Streifel and Marshall (1997) recommend the range of 0.035 in. w.g. or 8.0 Pa ± 0.02 in. w.g. or 5 Pa for protective and 0.01 in. w.g. or 2.5 Pa ± 0.006 in. w.g. or 1.5 Pa for airborne infection isolation.

However, since the room leakage area is not known before construction and cannot be guaranteed and the pressurization is an arbitrary figure that creates flow, it is recommended that the airflow difference be specified instead of pressure differential. The Centers for Disease Control and Prevention (CDC) guidelines recommend 50 cfm or 10% difference between supply and exhaust, whichever is larger.

To help get the airflow in the desired direction, the corridor can be either positively or negatively pressurized. Also, to reduce the eventual escape of contaminated air during the opening and the closing of the door, anterooms are provided. To be effective, the anteroom should have positive air pressure in relation to the isolation room (CDC 1994).

Risk Assessment. In a hospital or a health care environment, health risks are abundant. The risks that can be controlled by the HVAC systems relate to the transmission of infectious airborne diseases of either bacterial (tuberculosis, legionnaires' disease), viral (varicela, influenza, chickenpox, measles), or fungal (aspergillosis) nature.

When the risk of contamination is present everywhere, it is not possible to eliminate all the risks. But the HVAC engineer's efforts must focus on the reduction of the risk of contamination through design. This effort must be coordinated with and must be supplemented by facility operating and administrative measures that include, but are not limited to, source management, activity management, cleaning, and maintenance.

The assessment of the degree of health risk regarding the transmission of airborne disease must be done for each space,

and the cost of the engineering measures to minimize this risk must be evaluated. This cost must be compared with the value of the health care expenditure avoided, and the system selection must be based on this comparison.

For example, the best engineering control for minimizing the risk of TB contamination can be achieved by exhausting the air to the outside. The 100% exhaust systems are inherently energy intensive. They are mandated by codes in the negative pressure isolation rooms and few other rooms. Although there are rooms, such as waiting rooms, where the risk of contamination from unknown and unsuspected cases of TB is very high, traditionally, these rooms are not exhausted to the outside on the account of their high energy consumption. The designer should assess the degree of risk, compare the cost of the medical treatment (for example, a case of tuberculosis costs approximately $100,000) with the cost of the supplementary energy spent by a 100% exhaust system, and select the type of system based on this comparison.

Acoustical Criteria. The definition of the acoustical control in creating the appropriate environment is expressed in the *1997 ASHRAE Handbook—Fundamentals* as follows: sound and vibration are created by a source, are transmitted along one or more paths, and reach a receiver. Treatments and modifications can be applied to any or all of these elements to achieve a proper acoustical environment that is free of noise and vibration.

- *Sources of noise*. To be able to design for an environment free of noise and vibration, the designer must first determine the conditions under which this control process takes place, such as the outdoor existing sources of noise or those other than HVAC noises generated in the building. They can be categorized as (1) equipment that moves in one way or another, powered by different sources of energy (i.e., electric, pneumatic, etc.), (2) fluids that flow in ductwork or piping and through accessory devices, and (3) electrical equipment in which magnetostriction (transformer hum) occurs.
- *Room sound criteria*. The HVAC engineer should also establish the goal of the sound and vibration control, the definition of an acceptable acoustical environment. Out of the four types of acoustical design criteria, A-weighted sound level (dBA), noise criterion (NC) curves, room criterion (RC) curves, and loudness (sones), the most adequate type is the RC curves because it was designed specifically for establishing HVAC system design goals (ASHRAE 1997). The indoor RC criteria must be determined for each type of space in the building.
- *Type of sound attenuator*. The quality of air that we breathe has became more and more important. Although the dissipative attenuators (sound traps with baffles filled with low-density mineral fiber insulation) are more effective than the reactive attenuators (sound traps made out of cavities that absorb incident sound energy based on resonator concept), the reactive attenuators (usually called the hospital type) are mandatory for hospitals. They are also recommended for other health care facilities for their role in minimizing the risk of accumulation and growth of microorganisms that find the fiber insulation an ideal place for their habitat.

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In some jurisdictions in the U.S., the current codes place clinics in a different code category than hospitals and consequently under other enforcing agencies. This results in less strict design criteria for clinics than for the hospitals with the same type of occupancy. In some jurisdictions, the clinics are built and operated at lower standards than the hospitals.

The application of the most stringent requirements prescribed for a specific occupancy must be followed by the designers—same occupancy, same design criteria, regardless of where the space is situated or under what code jurisdiction it falls.

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Except for ventilation, which is well defined in the current codes, other criteria important for the design of the mechanical rooms are not formally published at the beginning of the project. But a good designer would consider, analyze, and determine the following:

- the location and the adjacencies of the mechanical equipment rooms to avoid noise generation in the occupied spaces, escape of pollutants, and moisture penetration in the occupied spaces;
- easy room and equipment access to allow inspection, maintenance, repairs, and replacement;
- rooms housing equipment generating heat should have means of heat removal and temperature control;
- equipment must be provided with seismic restraint and vibration isolation as required by codes;
- equipment and equipment rooms must be equipped with safety devices as required by codes;
- future expansion needs.

The coordination with the architect is mandatory for the implementation of these design criteria.

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The normal operation of HVAC systems may be interrupted for numerous reasons: HVAC equipment failure (even the most well maintained piece of equipment will fail sooner or later), utility service interruption, catastrophic events, such as earthquakes, fire, or bio-terrorism. The questions that have to be posed and answered during the design criteria definition phase for each system separately are: (1) Does the system have to operate continuously? (2) If not, for how long can the interruption be tolerated?

In a hospital, most of the HVAC equipment has to operate continuously. The following are a few examples:

- The supply, return, and exhaust fans have to provide the ventilation air without interruption and have to ensure the pressure relationship between rooms.
- With large deviation between jurisdictions in the U.S., and depending on the winter design outdoor air temperature, the heating equipment has to maintain the design temperature in all sensitive areas—operating rooms, delivery rooms, recovery rooms, nursery, and intensive care—and reduced temperatures in other occupied areas.
- Although not required by codes in some jurisdictions, it is recommended that the same be applied to the cooling equipment serving the sensitive areas.

If there is a need for continuous operation, all the equipment in the system has to have a back up. The designers usually provide a second piece of equipment of the same size that will be readily available and automatically turned on to replace the failing equipment. The total installed capacity will be 200%.

A most economical way to provide the uninterrupted service is to install three pieces of equipment, each having 50% of the required capacity, instead of two pieces of equipment at 100% capacity each. This way, the installed capacity is only 150% of the needed capacity as opposed to 200%, most of the time resulting in substantial cost savings.

In case the interruption of a system's operation is not critical, the installation of a full backup is not necessary. However, the parallel installation of two or even three pieces of equipment, for a total of 100% capacity, can cover some of the load in case one of them fails.

Catastrophic Events. If the building is an essential one, meaning that its operation has to continue after an catastrophic event, special considerations have to be taken into account. Most of the hospitals or part of the buildings in a hospital complex are designed as essential buildings. They must have full backup for equipment, e.g., heating, cooling, air movement, pumping, etc., and for utilities, e.g., electricity, fuel, medical gas, and water.

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Changes in space utilization are current in health care facilities, and periods of ten years between remodeling are commonplace. The new spaces will require more medical equipment thus increasing the cooling loads.

The initial design must consider these future changes and must provide for them. There are many means of achieving this goal. We enumerate only a few here.

- oversizing the ductwork and the piping,
- providing spare equipment capacity or room for future equipment installation,
- designing the layout of the main ductwork in a loop, thus allowing the change of air terminal connections without ductwork modifications.

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The purpose and main benefit of commissioning is to provide fully functional building systems along with trained operation and maintenance personnel coincident with substantial completion and/or building occupancy. It also presents the advantage of revealing the deficiencies during construction when the contractor is still available on the site to correct them.

The commissioning process is discussed here only in relation to the design criteria. The following points have to be established and approved in agreement with the owner as part of the project design criteria:

- the owner's present and future capabilities for operation and maintenance;
- the owner's expectations of the commissioning process;
- which general stipulations must be included in the construction documents.

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Specific attention must be given to the design criteria related to the specific conditions for retrofit work in an existing construction. These must include the isolation of the space under construction from the existing space in operation. If necessary, special ventilation must be provided to avoid migration of dust and other pollutants from the area under construction to the area in operation.

The systems and their components must be designed for minimum energy consumption and cost. Heat recovery, electric demand shifting from peak to off-peak time of the day, gas cooling, renewable energy sources such as solar energy, and heat pumps are only few examples.

Maintenance costs can sometimes surpass the energy costs. System and equipment selection must be made so that they are easy to maintain and maintenance cost are minimized.

Ideally, the systems should be designed at minimum cost to save energy and to be maintained with minimum effort and cost. This ideal situation seldom occurs because systems that save energy usually cost more to buy and install. The variation of cost in one direction or another, between cost categories, for different system alternatives makes their selection difficult unless an economic evaluation is performed. The way this economic evaluation is conducted and systems are selected must be specified in the system design criteria.

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The cost-effectiveness of an investment can be assessed by many economic indicators, such as net savings, simple payback, savings-to-investment ratio, adjusted internal rate of return, etc.

To determine the relative cost-effectiveness of two or more project alternatives, the most comprehensive and straightforward economic method is the life-cycle cost (LCC) analysis. This method incorporates all the cost elements of an investment during its life cycle and is the standard method required by the Department of Energy's Federal Management Program (FEMP) for evaluating energy and water conservation investments in federal buildings. The method is described at length in the *Life-Cycle Costing Manual for the Federal Energy Management Program,* NIST Handbook 135. Handbook 135 is supplemented by the annually published *Energy Price Indices and Discount Factors for LCC Analysis*. It is also accompanied by the NIST computer software for performing life-cycle cost analysis of buildings and building systems.

The LCC method is the ideal economic method applicable to the comparison of the HVAC alternatives because, inherently, these alternatives include energy, water, and operation costs. Adhering to the federal program presents the advantage of a uniform method for economic analysis of HVAC alternatives and of readily available discount factors and price escalation rates for each region in the U.S., updated annually.

The method is specifically useful in the assessment of long-term cost-effectiveness of design alternatives that have different initial investment costs, energy, operating, maintenance, and repair costs, or different lives.

For the decision process, in addition to the life-cycle cost calculations, Handbook 135 recommends uncertainty assessment and sensitivity analysis.

The life-cycle cost analysis is labor intensive and is not usually paid for in the private industry. To minimize the calculations at a level where the HVAC engineers could use it and benefit from it in the normal course of design, a simplified version is presented here and summarized in Table 1.

The simplified method includes the following cost elements:

- initial investment cost for each alternative,
- equipment replacement cost and the year of replacement (if replacement occurs within the study period),
- annual energy costs,
- annual water costs (only if they vary from one alternative to another), and
- annual nonfuel operating, maintenance, and repair costs (OM&R).

To further simplify the calculations, any of the above cost elements can be reduced to only the costs that differ from one alternative to another. For example, if both HVAC alternatives use the same central plant, the costs related to the initial investment and operation of this plant could be excluded from the calculations. But if, for example, the chillers are different from one alternative to another, the costs associated with the chillers must be included in the calculations.

The present value of each of the annual costs is calculated based on

- the length of study period (usually 25 years) and
- the discount rate (either the annually published real DOE discount rate, exclusive of general inflation, or the investor's discount rate),

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Life-Cycle Cost Analysis for 25 Years—Los Angeles Location

Item	ALT 1 Waiting Rooms Air Recirculation	ALT 2 Waiting Rooms HEPA on Return Air	ALT 3 Waiting Rooms 100% Exhaust	ALT 4 Building HEPA on Return Air	ALT 5 Building 100% Exhaust
Investment Cost		3430	1000	7980	–3000
Electric Energy Cost					
Annual cost	105,557	106,493	107,730	108,079	111,149
FEMP UPV factor	15.92	15.92	15.92	15.92	15.92
Present value ($)	1,680,467	1,695,369	1,715,062	1,720,618	1,769,492
Cost of Gas					
Annual cost	1582	1582	1590	1582	2036
FEMP UPV factor	17.03	17.03	17.03	17.03	17.03
Present value ($)	26,941	26,941	27,078	26,941	36,673
Maintenance Cost					
Annual cost	0	2640	600	6120	–1000
FEMP UPV factor	17.22	17.22	17.22	17.22	17.22
Present value ($)	0	45,461	10,332	105,386	–17,220
Total Present Value	1,707,409	1,771,201	1,753,471	1,860,926	1,783,945

Based on NISTIR 85-3273-14r (Rev. 4/99), *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis* (NISTIR 1999).

by applying the following factors:

- the single present value (SPV) factor used to calculate the present value of future cash amount, such as equipment replacement costs, based on the year of replacement and the selected discount rate (from Table A-1 of the Annual Supplement to Handbook 135);
- the FEMP uniform present value (UPV) factors for each of the annual energy recurring costs at a nonconstant escalation rate, based on the DOE projections of energy escalation rate, according to the location of the project (from Tables Ba-1 through Ba-5 of the Annual Supplement of Handbook 135);
- the UPV factors of annually recurring costs based on the selected discount factor and the length of study period, applicable to annual nonfuel operating, maintenance, and repair costs (OM&R) and to water consumption and/or disposal (from Table A-2 of the Annual Supplement to Handbook 135).

The summation of all present values pertinent to an alternative constitutes the total present value of that alternative. The smaller present value alternative becomes the recommended alternative unless further intangible advantages have to be considered or sensitivity analysis must be performed.

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